

0-8106 853

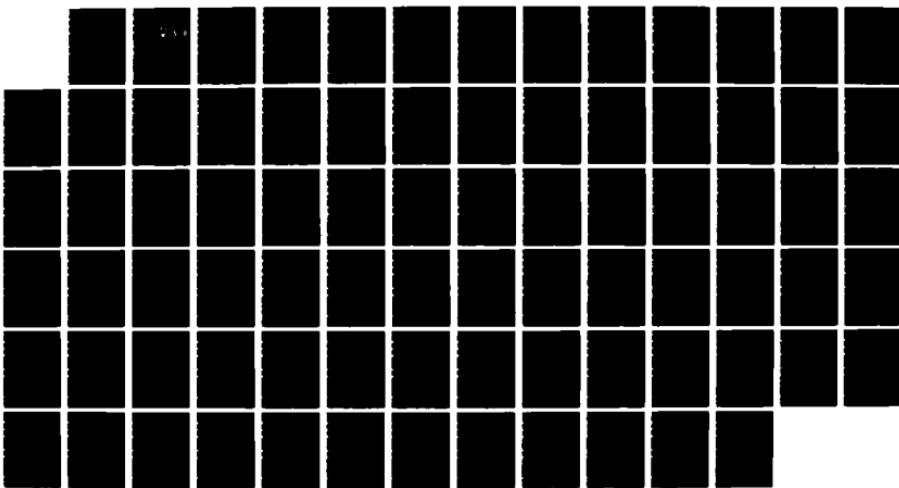
NRROSS (NAVY REMOTE OCEAN SENSING SYSTEM) - A FORCE  
MULTIPLIER(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA  
C L SPOHNHOLTZ SEP 87

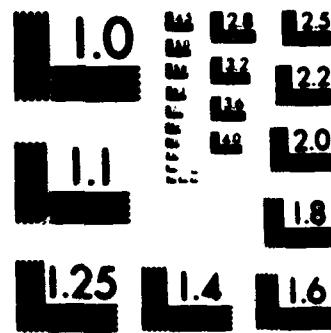
1/1

UNCLASSIFIED

F/G 17/8

ML





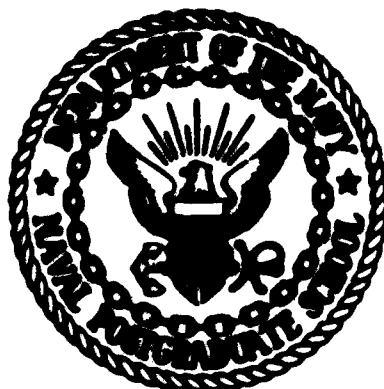
MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963 A

2  
DTIC FILE COPY

AD-A186 853

# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



DTIC  
ELECTED  
DEC 15 1987  
S D  
C&D

# THESIS

NROSS: A Force Multiplier

by

Cheryl L. Spohnholtz

September 1987

Thesis Advisor:

L. K. Crumback

Approved for public release; distribution is unlimited.

87 12 9 15

SECURITY CLASSIFICATION OF THIS PAGE

AD-B106 553

## REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		1b RESTRICTIVE MARKINGS		
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b DECLASSIFICATION/DOWNGRADING SCHEDULE		5 MONITORING ORGANIZATION REPORT NUMBER(S)		
8 PERFORMING ORGANIZATION REPORT NUMBER(S)		6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School		
6b OFFICE SYMBOL (If applicable) Code 74		7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School		
8c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000		7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000		
8d NAME OF FUNDING/SPONSORING ORGANIZATION		8e OFFICE SYMBOL (If applicable)		
8f ADDRESS (City, State, and ZIP Code)		9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
		10 SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO	PROJECT NO	
		TASK NO	WORK UNIT ACCESSION NO	
11 TITLE (Include Security Classification) <b>NROSS: A FORCE MULTIPLIER</b>				
12 PERSONAL AUTHOR(S) <b>Spohnholtz, Cheryl L.</b>				
13a TYPE OF REPORT <b>Master's Thesis</b>	13b TIME COVERED FROM _____ TO _____	14 DATE OF REPORT (Year Month Day) <b>1987 September</b>	15 PAGE COUNT <b>79</b>	
16 SUPPLEMENTARY NOTATION				
17 COSAT CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) <b>NROSS, environmental satellite, oceanographic satellite, remote sensing, Navy space</b>		
FIELD	GROUP	19 ABSTRACT (Continue on reverse if necessary and identify by block number)  This thesis examines the Navy Remote Ocean Sensing System (NROSS) as a force multiplier and shows why the Navy needs an oceanographic satellite. A history of oceanographic remote sensors provides background and is followed by a review of current and planned environmental satellites. The capabilities of these satellites are compared to Navy tactical requirements and deficiencies are noted. Finally, NROSS is discussed, and a look to the future shows why, more than ever, the Navy needs NROSS.	20 DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION <b>Unclassified</b>
22a NAME OF RESPONSIBLE INDIVIDUAL <b>LTCOL Linda K. Crumback</b>		22b TELEPHONE (Include Area Code) <b>408-646-2772</b>	22c OFFICE SYMBOL <b>Code 39</b>	

Approved for public release; distribution is unlimited

**NROSS: A Force Multiplier**

by

**Cheryl L. Spohnholtz  
Lieutenant, United States Navy  
B.S., United States Naval Academy, 1980**

Submitted in partial fulfillment of the requirements for the degree of

**MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY  
(SPACE SYSTEMS OPERATIONS)**

from the

**NAVAL POSTGRADUATE SCHOOL  
September 1987**

Author:

Cheryl L. Spohnholtz

Cheryl L. Spohnholtz

Approved by:

Linda K. Crumback

Linda K. Crumback, Thesis Advisor

Andreas K. Goroch

Andreas K. Goroch, Second Reader

Rudolf Panholzer

Rudolf Panholzer, Chairman Space Systems Academic Group

Gordon E. Schacher

Gordon E. Schacher, Dean of Science and Engineering

## ABSTRACT

This thesis examines the Navy Remote Ocean Sensing System (NROSS) as a force multiplier and shows why the Navy needs an oceanographic satellite. A history of oceanographic remote sensors provides background and is followed by a review of current and planned environmental satellites. The capabilities of these satellites are compared to Navy tactical requirements and deficiencies are noted. Finally, NROSS is discussed, and a look to the future shows why, more than ever, the Navy needs NROSS.

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail Com/ or Special
A-1	



## TABLE OF CONTENTS

I.	INTRODUCTION . . . . .	6
A.	STATEMENT OF THESIS . . . . .	6
B.	THESIS STRUCTURE . . . . .	7
II.	NAVY REQUIREMENTS FOR ENVIRONMENTAL DATA . . . . .	9
A.	INTRODUCTION . . . . .	9
B.	ENVIRONMENTAL PARAMETERS AFFECTING MISSION SUCCESS . . . . .	10
C.	NAVAL WARFARE REQUIREMENTS . . . . .	11
D.	CRITICAL PARAMETERS . . . . .	16
E.	SUMMARY . . . . .	17
III.	HISTORICAL BACKGROUND . . . . .	18
A.	INTRODUCTION . . . . .	18
B.	EARLY BEGINNINGS . . . . .	18
C.	EARLY SENSORS IN VISIBLE/INFRARED REMOTE SENSING . . . . .	19
D.	EXPERIMENTAL SENSORS IN THE MICROWAVE REGION . . . . .	21
E.	MICROWAVE REMOTE SENSING IN THE EARLY EIGHTIES . . . . .	27
F.	SUMMARY . . . . .	29
IV.	EXISTING/PLANNED ENVIRONMENTAL SATELLITE SYSTEMS . . . . .	31
A.	INTRODUCTION . . . . .	31
B.	CURRENT SYSTEMS . . . . .	32
1.	U.S. Programs . . . . .	33
2.	Foreign Programs . . . . .	38
C.	FUTURE SYSTEMS . . . . .	41
1.	U.S. Systems . . . . .	41
2.	Joint U.S. / Foreign Programs . . . . .	43

3. Foreign Programs . . . . .	44
D. SUMMARY . . . . .	46
 V. DEFICIENCIES IN SUPPORT FOR NAVY REQUIREMENTS	48
A. INTRODUCTION . . . . .	48
B. METHODOLOGY . . . . .	48
C. COMPARISONS OF AVAILABLE SENSORS TO DATA REQUIREMENTS . . . . .	49
D. SUMMARY . . . . .	55
 VI. THE NAVY REMOTE OCEAN SENSING SYSTEM (NROSS)	56
A. INTRODUCTION . . . . .	56
B. NROSS MISSION AND PARTICIPANTS . . . . .	56
C. NROSS HISTORY . . . . .	58
1. The Acquisition Process . . . . .	58
2. Reaction to NROSS Cancellation . . . . .	61
3. NROSS Revived . . . . .	62
D. NROSS INSTRUMENTATION . . . . .	63
E. SUMMARY . . . . .	66
 VII. SUMMARY: A LOOK TO THE FUTURE . . . . .	67
A. INTRODUCTION . . . . .	67
B. A NEW ENVIRONMENT . . . . .	67
C. COST FACTORS . . . . .	68
D. SUMMARY . . . . .	69
 LIST OF REFERENCES . . . . .	70
INITIAL DISTRIBUTION LIST . . . . .	77

## I. INTRODUCTION

### A. STATEMENT OF THESIS

Why does the Navy need an oceanographic satellite? An oceanographic satellite is a force multiplier that better enables the Navy to accomplish its mission. The Navy Remote Ocean Sensing System (NROSS) is currently the most viable candidate to fulfill Navy requirements for oceanographic remote sensing from space.

The mission of the Navy is to ensure free and unimpeded access to the world's oceans. This task is accomplished through worldwide deployment of naval forces. "Oceanographic characteristics (ocean thermal structures, fronts and eddies, internal waves and ice formations) have a profound influence on force deployment and weapon system employment decisions in naval operations." [Ref. 1] To support tactical naval operations, the oceanographic data must meet the following requirements:

1. Global coverage - The U.S. Navy operates in every ocean of the world and therefore requires coverage of all ocean areas.
2. Real or near-real time receipt of data - To make the information tactically relevant, it must be current.
3. All-weather, day/night coverage - The U.S. Navy is on duty twenty-four hours a day, in all kinds of weather.

Satellite sensors can best meet these requirements. Specifically, NROSS was designed by the Navy to provide timely, global all-weather coverage of oceanographic parameters.

Critics of a Navy-owned satellite cite several reasons for their opposition:

1. Existing Department of Defense (DOD) and civilian environmental satellites provide ample oceanographic data.

2. The cost of the satellite is too prohibitive in the current era of budget austerity.
3. In-situ and aircraft observations are sufficient.
4. The money could be better used for more urgent Navy needs.

This thesis will counter these arguments and prove that the Navy has a valid requirement for its own oceanographic satellite.

#### B. THESIS STRUCTURE

This thesis will have seven chapters: Introduction, Navy Requirements for Environmental Data, Historical Background, Existing/Planned Environmental Satellite Systems, Deficiencies in Support for Navy Requirements, The Navy Remote Ocean Sensing System, and Summary: A Look to the Future.

Chapter I - This chapter provides the framework for the thesis. It identifies the problem and sets the stage for the following chapters.

Chapter II - For NROSS to be an effective force multiplier, it must improve the Navy's ability to protect the seas. Each warfare area has specific requirements for oceanographic data. This chapter specifies what the warfare area requirements are and how NROSS will meet those requirements.

Chapter III - In order to understand the value of NROSS to the Navy and how it evolved, a history of oceanographic sensors will be presented. Satellite design is extremely dependent on what has been done before, and these experimental satellite sensors and systems form the heritage for NROSS.

Chapter IV - There are many environmental satellites in the world today, and the Navy receives information from many of them. This chapter will focus on existing systems and look at upcoming

**satellites that could help to satisfy Navy requirements for oceanographic data.**

**Chapter V - Even with the variety of existing environmental satellites, Navy requirements are not fulfilled. This chapter will identify the deficiencies with the current satellite systems, and examine the future system to see if they might meet the requirements.**

**Chapter VI - After reviewing the history, current systems, and deficiencies, the Navy realized it had an outstanding requirement for oceanographic data. The Navy Remote Ocean Sensing System is the proposed solution. This chapter will look at NROSS: the history and the satellite.**

**Chapter VII - Finally, a summary and outlook to the future will be presented. The new threat environment will be briefly examined. The need for oceanographic data is becoming more important and NROSS is the best method to acquire that data.**

## II. NAVY REQUIREMENTS FOR ENVIRONMENTAL DATA

### A. INTRODUCTION

The mission of the Navy is to maintain free and unimpeded access to the world's oceans. This requires global deployment of naval forces. Inadequate environmental data can adversely impact the tactical employment of those forces, so specification of Navy requirements for environmental data is necessary to ensure adequate support. Adm. James D. Watkins, former Chief of Naval Operations, stated "Today and in the future certain senses are critical to our Navy's survivability and capabilities. A Navy of 600 strong ships would...be blind if it lacked information about weather." [Ref. 2]

An operational requirement is defined in JCS Pub 1 as "an established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions, and tasks." [Ref. 3] Navy requirements for environmental data must be expressed in mission terms to justify the expense of fulfilling the need. The specification of Navy requirements for environmental data from space is found in "Operational Requirement Satellite Measurement of Oceanographic Parameters" (SMOP/OR W0527-OS) which was approved 10 February 1977.

In order to provide timely, accurate environmental data in support of naval warfare tactical requirements, five elements are necessary:

1. Scientifically accurate environmental forecast models.
2. Fast, large capacity computers.
3. Real time global atmospheric and oceanographic data base.

4. Skilled personnel.

5. Effective communications. [Ref. 4]

Currently, the most critical element is the real time global atmospheric and oceanographic data base. The atmospheric data base is fairly well established, but oceanographic data is sorely lacking. The need to obtain proper sampling of the data required for analytical and numerical models is probably the most significant limitation on advances in physical oceanography. [Ref. 5] In-situ data from ships and buoys is limited and restricted to discrete areas (most often located along established ocean routes). Additionally, 90-95 % of that data comes from foreign sources which will likely be unavailable in times of conflict [Ref. 4]. Existing satellite sensors are optimized for cloud observation, not ocean sensing. These problems have hindered the ability to fulfill Navy requirements with existing systems.

**B. ENVIRONMENTAL PARAMETERS AFFECTING MISSION SUCCESS**

Environmental parameters can be divided into two broad categories: atmospheric and oceanographic. Atmospheric parameters affecting the ability to perform naval warfare missions include cloud cover, precipitation, air temperature and humidity profiles, vector winds, visibility, and air pressure/density. Oceanographic parameters related to mission accomplishment include sea ice, sea surface temperature, vertical ocean thermal structure, sea state, marine winds, waves (period, direction, and significant height), surface currents, bathymetry, tides, and sea surface topography. These parameters will be related to specific warfare areas.

### C. NAVAL WARFARE REQUIREMENTS

The value of NROSS to the Navy can be measured by its ability to assist in the accomplishment of each warfare area mission. In the Planning and Reference Guide for Naval Oceanography from Space, warfare areas are defined and important environmental parameters are identified. This section is paraphrased directly from that source.

There are twelve warfare areas/subareas that are affected by environmental data: Sea Based Strategic Strike, Anti-Submarine Warfare, Anti-Air Warfare, Anti-Surface Ship Warfare, Amphibious Warfare, Tactical Air Strike Warfare, Special Warfare, Mine Warfare, Ocean Surveillance, Electronic Warfare, Command, Control and Communications, and Logistics. Each of these areas will be defined and environmental parameters identified. [Ref. 6]

Sea based strategic strike is the role of the Navy nuclear ballistic missile submarine (SSBN). Because of its ability to operate covertly, the SSBN is the least vulnerable leg of the U.S. strategic triad. Its ability to remain an effective deterrent depends on detection avoidance and accurate missile launch.

Environmental factors affect both areas:

1. Knowledge of the ocean's thermal structure affects the SSBN's ability to avoid detection and to effectively conduct sonar searches.
2. Under-ice operations require knowledge of location and thickness of sea ice.
3. To accurately fire submarine launched ballistic missiles (SLBM's), data on the winds and density of the upper atmosphere is needed.
4. The stability of the SSBN at launch depth could be adversely affected by a high sea state.
5. Ambient noise caused by marine winds affect sonar utility.
6. Gravity influences the SLBM throughout its flight.

Anti-submarine Warfare (ASW) is the use of ships, submarines, and aircraft to deny the enemy effective use of his submarines. ASW is one of the warfare areas most sensitive to oceanographic parameters, because its target operates in the ocean depths. Some of these environmental parameters include:

1. Accurate understanding of the ocean thermal structure (ducts, gradients, and inhomogeneities such as fronts and eddies) permits greatly improved acoustic search and hiding.
2. Tactical sonar is degraded in high sea states due to ambient noise and dome quenching.
3. Anomalies in the earth's magnetic field degrade performance of airborne magnetic anomaly detectors.
4. Sea ice greatly affects acoustic propagation and ambient noise. It precludes use of surface ASW platforms and degrades air ASW.
5. Weather elements (winds, clouds, precipitation) can hamper or prevent use of surface and air ASW platforms. Employment of acoustic sensors is difficult and launch of LAMPS helicopters and/or carrier based aircraft may be prevented.

Anti-air warfare is that action required to destroy or neutralize the enemy air and missile threat. It includes such measures as use of interceptors, bombers, anti-aircraft guns, surface or air-to-air missiles and electronic countermeasures. Atmospheric parameters are probably the most significant information required for this warfare area.

1. Radar search and electronic countermeasures are affected by fluctuations in atmospheric temperature and humidity.
2. Carrier flight operations are impaired by low visibility and precipitation.
3. Size and density fluctuations in atmospheric particles affect electro-optic sensors and weapon system performance.
4. Guided missile performance and chaff use are affected by winds aloft.
5. Flight operations can be cancelled or delayed due to high sea state.

6. Aircraft contrails can be detected using upper atmosphere temperature and humidity profiles.

As the size of the U.S. Navy approaches 600 ships and the Soviet Navy continues to expand, anti-surface ship warfare (ASUW) increases in importance. ASUW is the use of aircraft, ships, and submarines to deny the enemy use of its ships while defending friendly surface ships. Improved over-the-horizon weapons systems require knowledge of the environment.

Parameters affecting ASUW include:

1. Surface search radar is affected by atmospheric temperature and humidity profiles which can create blind spots and anomalous refraction. A high sea state can degrade radar return with clutter.
2. Electro-optic and infrared weapon systems and forward looking infrared devices performance on target is decreased by obstructed visibility (smoke, clouds, precipitation).
3. High sea state and marine winds impact ship handling and safety and the ability to launch aircraft. They must also be considered when selecting the mode for cruise missile attack.
4. Gunfire accuracy is affected by winds aloft.
5. The performance of acoustic homing torpedoes is influenced by the ocean thermal structure.

The environment impacts heavily on the amphibious warfare area. Amphibious warfare is the use of naval and landing forces to attack a hostile shore and secure a beachhead. Some of the environmental factors affecting amphibious warfare are:

1. Currents and tides, coastal bathymetry and geology, and beach slope and firmness directly influence the ability to move personnel and equipment ashore.
2. Landing craft (boats, air-cushion vehicles, and helicopters) are affected by local weather elements (wind, sea state, visibility and precipitation).
3. Ability to remain covert from overhead reconnaissance systems operating in the visible and infrared regions is dependent on cloud cover.

4. Mechanized heavy equipment require adequate ground support which can be determined by soil moisture.
5. Shore bombardment with naval gunfire is affected by winds aloft.

Tactical Air/Strike Warfare is the use of naval aircraft to neutralize or destroy enemy targets on land. One of the most recent examples of TACAIR was the bombing of Libya on 14 April 1986. Atmospheric parameters are extremely important in this warfare area.

1. Cloud cover/visibility/precipitation are valuable for avoiding detection on target approach but hamper accurate weapons delivery (especially laser guided ordnance).
2. Weather elements (sea state and marine winds) determine ability to launch carrier-based aircraft.
3. The atmospheric temperature and humidity profiles impact radar propagation and can affect the ability of enemy radar to detect incoming strikes.
4. If nuclear weapons are used, the radiation fallout pattern and egress route are determined by wind direction.
5. Enemy AAW forces can detect aircraft contrails caused by water vapor condensation in the upper atmosphere.
6. Atmospheric density/pressure influences the ability to avoid radar detection and conduct a low level approach.

Special warfare is the use of unconventional often clandestine naval forces to conduct operations including (but not limited to) surveillance and reconnaissance in and from restricted waters. Because of the wide variety of activities encompassed in this warfare area, environmental requirements are tailored for each mission. Use of cloud cover, low visibility and precipitation for covert missions is an important requirement of most missions.

Mine Warfare is the strategic and tactical use of mines and mine countermeasures. U.S. capabilities in this area are currently undergoing scrutiny due to the

mine threat in the Persian Gulf and Gulf of Oman. The environment plays an important part in this area:

1. The ability to lay and/or sweep mines is dependent on wind and sea state.
2. Choice of mine, proper setting, and position and depth of moor is determined by hydrographic effects.
3. When submarines are used to lay mines, the ocean thermal structure helps to determine detectability.

Military actions involving the use of electromagnetic energy to detect, classify and localize enemy forces fall in the realm of electronic warfare. The electromagnetic spectrum is highly susceptible to atmospheric parameters:

1. The temperature and humidity of the atmosphere determines its refractivity, which affects the propagation of electronic emissions.
2. Chaff dispersion and direction of movement depends on winds aloft.

Ocean Surveillance is the use of systematic observations of ocean areas by local or overhead sensors to detect, locate and classify targets. It is the first and crucial step that must be accomplished for any of the other warfare areas to be successful, because destruction of a target cannot occur if target location is unknown. Environmental parameters have a significant impact on the ability to conduct ocean surveillance:

1. Undersea surveillance arrays are affected by the ocean thermal structure.
2. Geological structures and bathymetry affect long range low frequency sound propagation.
3. Visual and infrared sensors on aircraft and satellites are blinded by cloud cover and degraded by low visibility and precipitation.
4. Increased ambient noise caused by storm generated wind and high seas degrades array performance.
5. Acoustic array location and orientation can be altered by ocean currents.

6. Knowledge of sea ice distribution is critical to developing an understanding of under-ice sound propagation and ambient noise levels.

Command, Control and Communication (C3) is the heart of all warfare activity. C3 is the support of decision making and resource management in the accomplishment of a mission.

1. Weather influences most tactical decisions (as seen above in previous warfare area discussions).
2. Worldwide electronic communications is affected by atmospheric temperature and humidity profiles and solar activity.
3. Naval planning requires the use of long term forecasts (5-10 days) to determine whether an operation should be undertaken.

Providing support to the operating forces in the form of ordnance, provisions, equipment and spare parts is the job of logistics. The ability to move supplies safely and efficiently from warehouse to the operating forces can be greatly affected by the environment:

1. Optimum ship track routing uses information on currents, wind, sea state, and storm locations to determine the best ocean route.
2. Use of cloud cover can decrease probability of enemy detection.
3. Use of ocean temperature data can assist in avoiding acoustic detection.
4. Sea ice boundaries determine ice-free transit areas and can be used for advantageous acoustical routing.
5. Tidal storm surges affect ability to onload supplies in severe weather.

#### D. CRITICAL PARAMETERS

The environmental parameters required by naval warfare areas as discussed above were reviewed in May 1987 by the Space Oceanography Group of the Office of the Chief of Naval Research in coordination with the Oceanographer of the Navy. The top ten parameters are listed below in decreasing order of priority.

Following each parameter is its relative overall military priority as identified in "Military Requirements for Defense Environmental Satellites" (MJCS 154-86, dated 1 August 1986).

1. Sea Surface Temperature and Ocean Vertical Temperature Profile <37>
2. Wind (horizontal and vertical components) <4>
3. Ocean Waves (significant wave height, amplitude, wavelength, and direction) <39>
4. Sea Ice (cover, thickness, type, roughness and leads and bergs) <36>
5. Atmospheric Vertical Temperature Profile <2>, Atmospheric Humidity Profile <3>, Liquid and Solid Water Content <8>
6. Cloud coverage, type, and layers (thickness) <1>
7. Ocean Current Profile (speed and direction) <44>, Near Shore Currents (speed and direction) <43>, and Ocean Surface Currents (speed and direction) <44>
8. Ocean Optical (extinction/scattering profiles) <NA>
9. Visibility (aerosol concentration and size) <6>
10. Shallow Water Bathymetry <41> [Ref. 7]

It is clear that some of the most critical Navy parameters are not a high priority in the overall picture of military requirements. This is one of the reasons the Navy is attempting to launch a Navy specific oceanographic satellite.

#### E. SUMMARY

It is evident that environmental parameters have a great impact on force application in all of the above warfare areas. Although many atmospheric parameters are available using existing satellite systems, oceanographic parameters are less available. The next chapter will examine early efforts in remote sensing of the ocean to discover where the available sensor technology came from.

### III. HISTORICAL BACKGROUND

#### A. INTRODUCTION

Navy requirements in the area of remote sensing of environmental data from space are based on a solid background of scientific research, experimental satellite programs, and existing environmental systems. The technology has been proven over the past twenty years and the concepts are valid. This chapter will review the history of U.S. remote sensing of oceanographic data from space.

#### B. EARLY BEGINNINGS

Since the launch of the first artificial earth satellite SPUTNIK in October 1957, the application of satellites to various scientific disciplines has been explored. The concept of oceanography from space was first investigated at a conference chaired by Dr. Gifford C. Ewing at the Woods Hole Oceanographic Institution in 1964. Meteorologists were already receiving important weather data from space and oceanographers hoped to expand upon their experiences. Many advanced concepts of remote sensing were discussed at the conference, including satellite altimetry, microwave radiometry, satellite radars, multi-spectral imagery and scatterometers. These ideas formed the basis for application of remote sensing from space to oceanography. For his efforts in the field, Dr. Ewing is sometimes called the father of oceanography from space. [Ref. 8, p. 14]

In 1969, NASA held two workshops on oceanography from space to plan for future satellite sensors. The first workshop, held at Williamstown, Massachusetts, resulted in a document titled "The Terrestrial

Environment Solid Earth and Ocean Physics, Applications of Space and Astronomic Techniques." The techniques discussed at this conference formed the groundwork for the development of the first oceanographic satellite, SEASAT. From the second workshop came a report called "The Color of the Oceans", and this report was the basis of biological oceanographic sensor development. These two documents provided the framework for NASA's oceanographic programs in the 1970's. [Ref. 8, p.15]

#### C. EARLY SENSORS IN VISIBLE/INFRARED REMOTE SENSING

The sixties and early seventies saw increased interest in space-based remote sensing for oceanographic purposes. Early remote sensors, though primarily intended for meteorological phenomena, also provided information on oceanographic parameters during cloud free observations. The National Aeronautics and Space Administration (NASA) took the lead in environmental remote sensing research when it launched its NIMBUS satellite series. These satellites acted as test platforms for new meteorological sensors.

[Ref. 9] See Table 3.1.

NIMBUS 1 (1964) and NIMBUS 2 (1966) carried the Advanced Vidicon Camera System (AVCS). AVCS was designed to provide high resolution cloud cover images, but in cloud free areas images of the ocean gave information on icebergs and ice edge.

The High Resolution Infrared Radiometer (HRIR) on NIMBUS2 2 identified temperature patterns of lakes and ocean currents, and the data was read out real time to automatic picture transmission stations. The improved HRIR on NIMBUS 3(1969) provided the first vertical temperature profile data on a global basis (including

TABLE 3.1  
SUMMARY OF EXPERIMENTS ON NIMBUS SATELLITES

	N I M B U S						
	1	2	3	4	5	6	7
NUMBER OF EXPERIMENTS	3	4	9	9	6	9	9
NUMBER OF SPECTRAL CHANNELS	3	8	28	43	34	62	79
SPECTRAL REGIONS							
VISIBLE	X	X	X	X	X	X	X
INFRARED	X	X	X	X	X	X	X
FAR INFRARED		X	X	X	X	X	X
ULTRAVIOLET			X	X		X	X
MICROWAVE					X	X	X

<u>SATELLITE</u>	<u>EXPERIMENT MENTIONED IN TEXT</u>
NIMBUS 1	AVCS
NIMBUS 2	AVCS, HRIR
NIMBUS 3	HRIR
NIMBUS 4	THIR
NIMBUS 5	ESMR, THIR
NIMBUS 6	ESMR, THIR
NIMBUS 7	CZCS, SMMR, THIR

[Ref. 9, p. 77]

coverage of sea surface temperatures in cloud free areas).

NIMBUS 4 (1970) flew the first Temperature Humidity Infrared Radiometer (THIR), the follow-on to the HRIR. THIR provided improved sea surface temperature discrimination. Under cloud free conditions, the sensor detected the division between the Gulf Stream and the colder water near the shore. Changes in the Gulf Stream could be mapped on a daily basis [Ref. 10, p. 239]. Improved versions of THIR were flown on NIMBUS 5, 6 and 7.

#### D. EXPERIMENTAL SENSORS IN THE MICROWAVE REGION

Where the sixties had emphasized visible and infrared techniques, the seventies began the use of microwave sensors and their application to oceanography from space. Use of the microwave region allows all weather, twenty-four hour coverage of the earth's surface. Because of its ability to see through clouds, the microwave region is especially applicable to sensing ocean parameters.

NASA continued to launch its NIMBUS satellites and expanded the sensor suite to microwave instruments. The electrically scanning microwave radiometer (ESMR) on NIMBUS 5 (1972) was the first U.S. microwave sensor. It provided data on ice cover and boundaries of the polar regions. NIMBUS 6 (1975) also carried the ESMR. [Ref. 8, p. 399]

NIMBUS 7 (1978), the last of the series, carried two new sensors with oceanographic applications. The first, the scanning multi-channel microwave radiometer (SMMR), provided information on ocean and ice dynamics and ocean surface conditions. This instrument, which continues to operate long after its design life, has provided extensive data sets for algorithm testing and

refinement. It is the same instrument that was carried on SEASAT (see below). Additionally, NIMBUS 7 flew the first coastal zone color scanner (CZCS), a sensor designed to measure chlorophyll concentration, sediment, temperature and spectral radiances from the oceans. [Ref. 9]

SKYLAB, the first U.S. space laboratory, was launched 14 May 1973 and manned for three separate time periods. Two microwave experiments, S193 and S194, were conducted on the manned SKYLAB space station in 1973. S193 was a combined radiometer /scatterometer /altimeter which operated at 13.9 GHz and used a scanning parabolic antenna. As a radiometer it was a passive sensor, but, when operating as a scatterometer or an altimeter, it was in the active mode. S194 was a passive radiometer with a fixed antenna that was designed to provide high precision measurements of the ocean's thermal emission. [Ref. 8, p. 400] These sensors demonstrated the potential of spaceborne microwave instruments for determination of surface wind and atmospheric and ocean sensing.

In April 1975, information on the geoid and sea height was detected by the first dedicated altimeter, flown on the Geodynamics Experimental Ocean Satellite (GEOS-3). GEOS-3 operated successfully until December 1978, providing a wealth of information to be used as input for scientific models of the geoid and the ocean. [Ref. 8, p. 400]

The experience gained from these microwave sensors, in addition to continued advances in visible and infrared technology, culminated in the launching of the first oceanographic satellite, SEASAT. (See Figure 3.1) SEASAT was launched in June 1978 and placed in a near circular orbit at an altitude of 790 kilometers and an inclination of 108 degrees. The

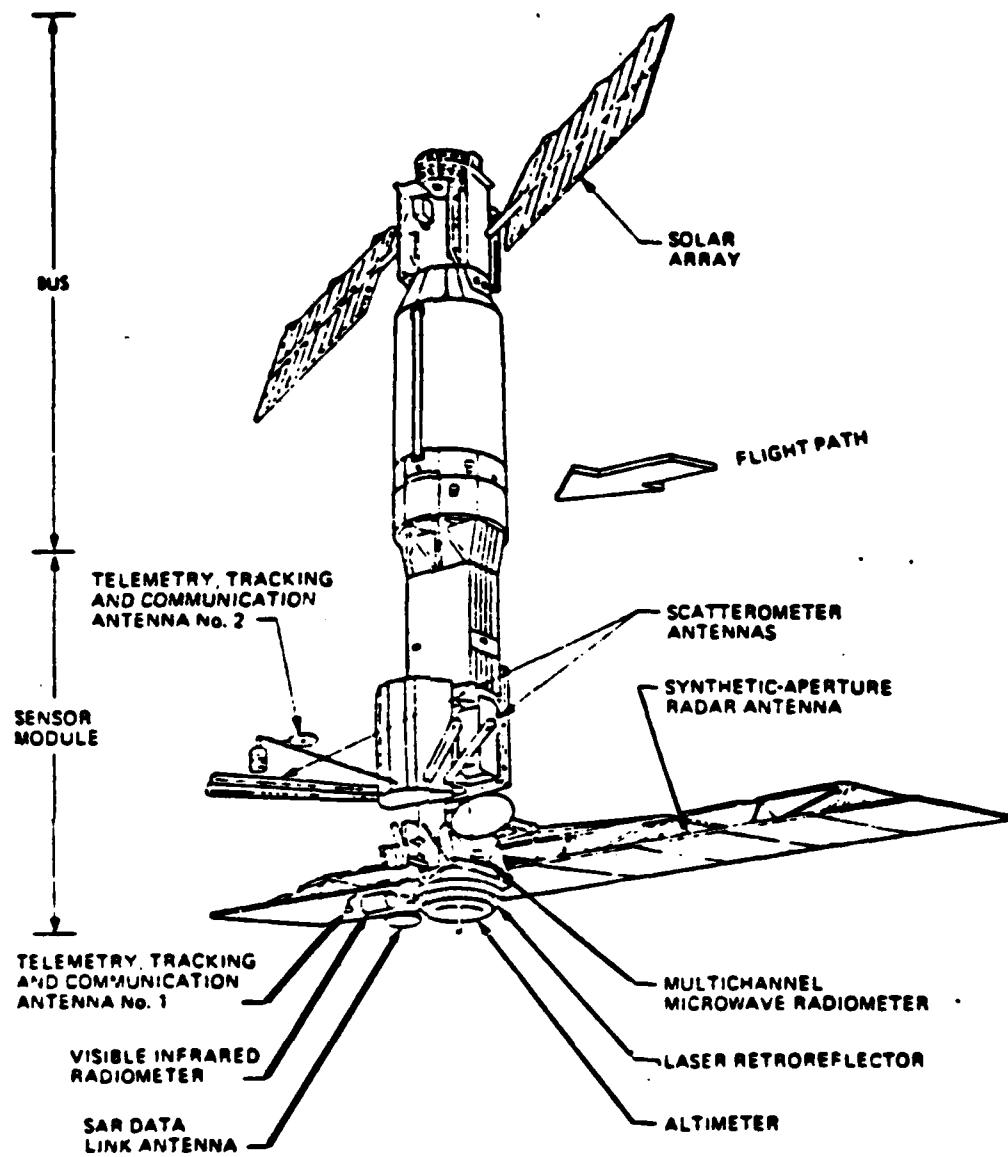


FIGURE 3.1  
SEA SATELLITE (SEASAT)

[Ref. 6, p. 4-21]

requirements for SEASAT were first identified by a users group consisting of Air Force, Navy, National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA) representatives. The satellite was established as a "new start" in 1975. [Ref. 11, p. 276] From the initial conception to the actual launch, SEASAT was designed for the user by the user.

SEASAT carried a five instrument sensor package including three active sensors and two passive sensors. The observed wavelengths were visible, infrared and microwave, thus providing concurrent coverage over a wide wavelength spectrum. Active sensors included a radar altimeter (ALT), a microwave scatterometer (SEASAT-A Scatterometer System, SASS) and a synthetic aperture radar (SAR). The passive sensors were a visible and infrared scanning radiometer (VIRR) and a scanning multi-channel microwave radiometer (SMMR). (See Table 3.2)

The sensors flown on SEASAT all had a direct heritage from previously orbited instruments with one exception: the synthetic aperture radar. Fundamentally a radar, the SAR used synthetic aperture techniques to make a 10 x 2 meter size antenna operate as a 3 km diameter antenna thus providing higher resolution images. The SAR was designed to obtain radar images of the sea surface revealing ocean wave patterns, information on water/land interaction, and data on ice and snow cover. Because of the high data rate (227 megabits/sec) required to achieve the desired resolution, no SAR data was recorded on board. Instead, the satellite observations were relayed in real time to ground stations when the SAR was in line of sight. The five ground sites were located in

TABLE 3.2  
SUMMARY OF SEASAT INSTRUMENTS

<u>NAME</u>	<u>SWATH WIDTH</u>	<u>FREQUENCY</u>	<u>MEASURED PARAMETER</u>
ALTIMETER (ALT)	2.4 TO 12 KM	13.5 GHZ	DYNAMIC HEIGHTS TO +10 CM AND SIGNIFICANT WAVE HEIGHT TO SAME ACCURACY FOR WAVES LESS THAN 20M.
SCATTEROMETER (SASS)	200-700 KM ON EITHER SIDE OF NADIR TRACK	14.6 GHZ	INFERENCE OF SURFACE WINDS FROM DOPPLER RETURN TO +2M/SEC AND +20 DEGREES DIRECTION OVER RANGE OF 4 TO 26 M/SEC.
SYNTHETIC APERTURE RADAR (SAR)	100 KM TO STARBOARD CENTERED 20 DEGREES OFF NADIR	1.275 GHZ	WAVES AND WAVE SPECTRA ICE BOUNDARIES, SEA STATE IN ALL WEATHER.
SCANNING MULTICHANNEL MICROWAVE RADIOMETER (SMMR)	600 KM TO STARBOARD	6.6, 10.7, 18, 21, AND 37 GHZ	ALL WEATHER MEASURE OF SEA SURFACE TEMPERATURE TO +2 K, SURFACE WIND SPEED TO +2 M/SEC.
VISIBLE/ INFRARED RADIOMETER (VIRR)	2200 KM CENTERED ON NADIR	.5-.9 um, 10.5-12.5 um	FEATURE IDENTIFICATION CLOUD AND SURFACE TEMPERATURES.

[Ref 8, p. 47]

Alaska, California, Florida, Newfoundland, Canada and Oak Hanger, England. Since no stations were located in the southern hemisphere, no SAR imagery of that area was received. [Ref. 12]

The radar altimeter on SEASAT was derived from earlier versions flown on SKYLAB and GEOS-3. ALT was developed to measure satellite altitude above the sea surface, significant wave height and surface wind speed, and to use the data obtained to refine the marine geoid. In an analysis of the ALT data, John R. Apel of the Applied Physics Lab confirmed altimeter retrieval of a wide variety of geophysical features including ocean geoid, boundary current speeds and positions, wind speeds, wind wave and swell heights, and polar sea ice edge positions. [Ref. 13, p. 333]

The SASS consisted of four dual polarized fan beam antennas, each capable of transmitting and receiving radio signals at 14.6 GHz. It was designed to measure wind speed and direction over the ocean. SASS was a follow-on to the scatterometer that flew on SKYLAB (S193). The results of SASS provided the first global synoptic-scale maps of wind speed and direction. [Ref. 14, p. 570]

The purpose of the SMMR was the measurement of sea surface temperature, surface wind speed, atmospheric liquid and water vapor content, and ice characteristics. A passive sensor, it measured radiance at five frequencies: 6.6, 10.7, 18.0, 21.0, and 37.0 GHz, each at horizontal and vertical polarizations. To prevent interference with the other sensors, the SMMR only scanned a swath to the right of the satellite. Analysis of SMMR data revealed that the system was capable of measuring atmospheric water vapor to the same accuracy as radiosondes, but was less

precise in measurements of sea surface temperature and surface winds. [Ref. 15, pp. 463-476]

Another passive sensor and the only SEASAT instrument not to operate in the microwave region was the visible and infrared scanning radiometer. The VIRR provided image feature identification in support of the other four sensors and obtained thermal images of the ocean. [Ref. 16, p. 17]

Although SEASAT had a planned three year lifetime, it suffered an electrical failure on 10 October 1978 after just over 100 days in orbit. The shortened lifespan did not detract from the encouraging results obtained by the SEASAT sensor suite:

After 1-1/2 years of intensive analysis...a multidisciplinary team of scientists, engineers, and analysts has concluded that the majority of the goals for measuring geophysical parameters have been met. Consequently, the overall project objective of demonstrating the concept of global, nearly all weather, microwave ocean surveillance capability has been accomplished. [Ref. 17, p. 3]

Although SEASAT has been dead for nine years, analysis of the data continues to this day. SEASAT was the significant breakthrough oceanographers had dreamed of back in 1964. The challenge for the next decade would be to take the proof of concept satellite and transform it into a fully operational oceanographic system.

#### E. MICROWAVE REMOTE SENSING IN THE EARLY EIGHTIES

Several proposals were raised concerning the next oceanographic system. NASA had originally planned a follow-on satellite called SEASAT-B, while the Department of Defense (DOD) suggested deployment of the Remote Ocean Measuring System (ROMS). Realizing that budget constraints would not support the launch of more than one satellite, a joint proposal was made. The National Oceanic Satellite System (NOSS) would be an operational ocean monitoring system for military

and civilian users. Three of the instruments would be of direct SEASAT heritage: the altimeter, scatterometer, and scanning multichannel microwave radiometer. Additionally, NOSS would carry a coastal zone color scanner (CZCS) for determination of ocean color. [Ref. 18, p. 31]

The NOSS program had three participants: NASA, DOD, and (NOAA). Initially the cost of the program was to be split equally, but the Office of Management and Budget refused to support the proposal unless the DOD/NOAA share was greater than NASA's share. The resulting breakdown follows :

NASA is lead agency for the program, which will be managed at the Goddard Space Flight Center. Fiscal year 1981 budget requests for NOSS include \$5.8 million from NASA, \$13.9 million from DOD, and \$6.4 million from NOAA. Future budgets are expected to be divided in a similar fashion. [Ref. 19, p. 18]

NASA would have been responsible for satellite development and launch, while NOAA would have provided satellite control and DOD would have received and processed the data. During the fiscal year 1982 budget process, DOD funding for NOSS was omitted due to more urgent Navy requirements. NASA and NOAA could not afford the program without DOD support so in 1981 NOSS was cancelled. [Ref. 20, p. 65]

With no satellite specifically deployed to provide oceanographic data, other options were examined. The Space Transportation System (commonly referred to as the Space Shuttle) has been used to conduct environmental observations on several occasions. The first experiments were conducted using the Shuttle Imaging Radar (SIR). Two versions of this synthetic aperture radar have flown on the shuttle. The first, SIR-A, was an experimental sensor flown on the second shuttle flight in November 1981. It operated for a total of eight hours during the three day mission and

provided limited coverage of the world's oceans.

[Ref. 12, p. 671]

SIR-B, an upgraded version of SIR-A, deployed in October 1984 into a 57 degree inclination orbit. The improvements in the system included:

- a. Adding a mechanical tilt mechanism to allow the antenna variable incidence angles between 15-60 degrees.
- b. Increased bandwidth.
- c. The addition of an antenna panel to increase antenna size.
- d. Use of a digital data processor instead of the data recorder on SIR-A.

This mission provided increased coverage of the oceans and northern fringes of the winter Antarctic ice pack.

[Ref. 12, p. 674]

In addition to observations by shuttle crews, in October 1984, Dr. Paul Scully-Power, a civilian oceanographer from the Naval Underwater Systems Center, initiated the Navy-sponsored oceanographer in space program. The success of that flight led the Navy to request future flights for Naval Oceanographic Observations on Shuttle (NOOS). The program was designed to be a continuing, at least once a year occurrence. [Ref. 6, p. C-6] The aftermath of the Challenger accident and resulting negative publicity concerning civilians in space will probably preclude any NOOS flights in the near future.

#### F. SUMMARY

Oceanographers were confident that SEASAT would usher in a new era of oceanographic remote sensing:

Undoubtedly oceanography will benefit greatly from future satellite and instrument packages modelled on SEASAT and its payload. Indeed, it is not too much to expect that oceanography...will undergo revolutionary growth in scale and practical significance as ocean-monitoring satellites increase our knowledge of maritime conditions by a veritable quantum leap. [Ref. 21, p.216]

Did this revolutionary growth occur? The next chapter will look at current and planned environmental satellites with possible oceanographic applications.

#### IV. EXISTING/PLANNED ENVIRONMENTAL SATELLITE SYSTEMS

##### A. INTRODUCTION

Navy requirements for environmental data are currently being supported by existing DOD and civilian environmental satellites. The only Navy satellite providing oceanographic data is GEOSAT (Geodetic Satellite). The ability of these satellites to fulfill Navy requirements will be examined. If current systems can provide sufficient information to the Navy, the need for NROSS would diminish.

In DOD, the Air Force is the executive agent for the Defense Meteorological Satellite Program (DMSP). The National Oceanic and Atmospheric Administration (NOAA) is the lead agency for the two civilian environmental programs: Geostationary Operational Environmental Satellite (GOES) and NOAA Advanced TIROS-N (Television and Infrared Observation Satellite). A third program, LANDSAT, is now operated by a commercial organization, Earth Observation Satellite Company (EOSAT). These four satellite systems make up the U.S. operational space program for earth observation.

Remote sensing is an international cooperative effort, with some successful instances of exchange of environmental data. Because of this, existing foreign environmental satellites will also be included in the group of satellites that could help fulfill Navy requirements for environmental data. Currently deployed are the European Space Agency's METEOSAT; France's SPOT; India's INSAT; and Japan's GMS and MOS-1. These satellites will be examined later in this chapter.

The year 1986 was catastrophic for the U.S. space program. With the tragic loss of the space shuttle Challenger on 28 January, the Space Transportation System was grounded. Latest estimates put the first launch of the revised shuttle in summer 1988. Other launch vehicle failures included the 18 April loss of a Titan 34D expendable launch vehicle (ELV) carrying a military satellite and the failure of a Delta ELV carrying GOES-G on 3 May. These accidents virtually halted U.S. space launches in 1986. The European Space Agency lost the use of its primary launch vehicle, the French Ariane rocket, when it was grounded following a launch failure in May 1986. The Ariane is scheduled to resume launches in the fall of 1987.

These events have negatively affected future environmental satellites. First, a delay in launch timetables has occurred. Second, many countries are re-evaluating their budget allocation for space systems. Finally, there is a new-found reluctance to build satellites which can only be shuttle-launched because the availability of the shuttle as a commercial launch system is questionable.

With that background in mind, environmental satellites planned for launch in the near future (1987-1995) will also be examined for their ability to meet Navy requirements. U.S., joint, and foreign programs will be reviewed.

#### B. CURRENT SYSTEMS

This section will describe the existing worldwide network of environmental satellites. U.S. systems will be presented first, followed by foreign programs.

## 1. U.S. Programs

### a. Geodetic Satellite (GEOSAT)

On 12 March 1985, the Navy's Geodetic Satellite (GEOSAT) was launched from Vandenberg Air Force Base into a near-polar 800 kilometer orbit. GEOSAT carries just one sensor, a SEASAT type altimeter. It is the first altimeter to be launched since SEASAT, and the only one of its kind to fly during this decade. GEOSAT is designed for a dual mission during its three year expected life: first, to accurately determine the marine geoid and second, to provide data on wind speed and significant wave height. When the geoid measurements were completed in 1986, the satellite was "repositioned into a repeat orbit to optimize oceanographic measurements of wave height and surface wind speed and to locate ocean fronts and eddies." [Ref. 22, p. 69]

### b. Defense Meteorological Satellite Program (DMSP)

The mission of DMSP is "to provide high quality weather and other environmental data in a timely fashion to the Armed Forces of the United States for tactical and strategic missions." [Ref. 23, p. 96] As such, it is the primary contender to satisfy Navy needs for environmental data. Security of DMSP data is achieved through the capability to encrypt the downlink transmission and protect the uplink transmission by a command receiver lockout system which only accepts commands from the three direct readout stations.

In 1969, the Navy joined DMSP and it became a tri-service program. The Navy Fleet Numerical Oceanographic Center began receiving DMSP data in the early seventies, and in 1971 the USS Constellation (CV-64) installed the first shipboard direct readout terminal, an AN/SMQ-6. [Ref. 24, p. 132] Subsequent

carriers received the AN/SMQ-10 Production Shipboard Receiving Terminal on a one-per-year basis until a total of eight terminals were installed.

Procurement ended at that time to prepare for introduction of the AN/SMQ-11 meteorological data receiver / recorder set. The Tactical Environmental Support System (TESS 3) will operate in conjunction with the AN/SMQ-11 and will be capable of receiving DMSP, NOAA, GOES WEFAX data (defined below) and NROSS data (when available).

The first TESS (3) systems are scheduled for installation in 1991. A total of 71 units are planned, including 44 shipboard and 27 shore-based units. 18 aircraft carriers, 4 battleships, 2 command and control ships, 5 LHA's, 7 LPH's, 6 LHD's and 2 AGF's will receive the terminals. [Ref. 25]

The DMSP has a history of innovation. In 1970, the Block 5A satellite series included the first 3-axis stabilized meteorological satellite. The first satellite of the Block 5D series, Block 5D-1 in 1976, was the first operational satellite to use on-board computers for command and control, attitude determination and control, ascent guidance and control, and redundancy/power management. [Ref. 24]

The first satellite of the current Block 5D-2 series of DMSP satellites, F6, was launched in 1982. Two satellites form the constellation and are phased so one crosses the equator at 0600 and the other at 2200. An Atlas E launch vehicle from Vandenberg Air Force Base sends the spacecraft into a 833 kilometer, 98.7 degree inclination orbit. The Block 5D-2 series has greater power available than earlier Block 5 satellites to support additional sensors. [Ref. 23] Deployed sensors include:

1. Operational Linescan System (OLS) - a two channel oscillating radiometer for global

day/night observation of cloud cover and temperature. In 1979, the infrared band was narrowed from 8-13 microns to 10.5-12.6 microns in response to Navy needs for improved sea surface temperature sensitivity [Ref. 24]

2. Special Sensor Microwave/Temperature (SSM/T) - a seven channel microwave temperature sounder operating at 50-60 GHz is used to retrieve the vertical atmospheric temperature profile.
3. Space Environment Sensor Suite (SESS) - a variety of sensors used to monitor the space environment including the ionospheric plasma and scintillation monitor (SSIE/S) and the precipitating electron/proton spectrometer (SSJ/4).
4. Special Sensor Microwave/Imager (SSM/I) - A new sensor was added to the Block 5D-2 series with the launch of F8 on 6 July 1987. Built by Hughes Aircraft Company, this sensor provides data on ocean surface wind speed, cloud water content, areas and intensity of precipitation, soil moisture, and ice age and coverage. It is a 7 channel, four frequency microwave radiometer that uses a conical scan pattern. It is the first jointly developed Air Force/Navy sensor and will also fly on NROSS.

c. Geostationary Operational Environmental Satellite (GOES)

GOES is the backbone of the U.S.

geostationary environmental system. The GOES constellation consists of two satellites, GOES-East at 75 west longitude and GOES-West at 135 west longitude. These two spacecraft provide near-continuous storm tracking, cloud analysis data, surface temperature data, space environment monitoring and remote sensor data relay.

The current series of satellites was first launched in 1975. GOES 1-3, built by Ford Aerospace Corporation, were spin stabilized cylindrical satellites with body-mounted solar cells for electrical power. The remaining five satellites in the series, built by Hughes Aircraft Company, are dual stabilized (part of the body is de-spun). Designed for a seven year life, several of the spacecraft have not met their lifespan. GOES 4 ceased to operate

after only two years and GOES-5 failed after three years due to an encoder lamp burnout. This has severely taxed the two-satellite constellation. From July 1984 until June 1987, GOES-6 operated alone. To cover the entire U.S., GOES-6 was shifted between 98 and 108 degrees west longitude, depending on the season. [Ref. 26] In February 1987, GOES-7 was successfully launched to complete the constellation.

GOES satellites provide continuous area coverage of the U.S. using four sensors:

1. Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) - two channels provide surface and cloud visual and infrared imagery (alternates between thermal 8-12 microns and water vapor channel at 6.7 microns). 12 infrared sounding channels provide the atmospheric temperature profile.
2. Data Collection Package (DCP) - designed to relay processed data from central weather facilities to APT equipped regional stations; also collects and retransmits data from remote earth-based sensors.
3. Weather Facsimile Broadcast (WEFAX) - a time shared system that transmits imagery and National Weather Service charts when imagery is not being acquired.
4. Space Environmental Monitor (SEM) - made up of three sensors including a magnetometer for magnetic field strength and direction; an x-ray sensor for monitoring solar flare activity; and an energetic particle sensor for detection of alpha particles, protons and electrons.

d. NOAA Advanced TIROS-N (NOAA)

The NOAA sun-synchronous, polar orbiting system is also a constellation of two satellites. This system is sometimes identified as POES (Polar Orbiting Environmental Satellite). The AM satellite provides morning coverage while the PM satellite provides afternoon coverage. The first Advanced TIROS-N satellite, NOAA-8, was launched on 29 March 1983. A total of six spacecraft will make up this series, which is scheduled to be launched through 1990.

[Ref. 27] Sensors on the current NOAA satellites include:

1. Advanced Very-High Resolution Radiometer (AVHRR/2) - five channel cross-track scanning radiometer providing data in the visible, near infrared and far infrared regions. Information on cloud cover and temperature, sea surface temperature, snow and ice, and water vapor is retrieved.
2. TIROS Operational Vertical Sounder (TOVS) - a subsystem with three sensors: a high resolution infrared sounder (HIRS), a stratospheric sounding unit (SSU) provided by the British Meteorological Office, and a microwave sounding unit (MSU).
3. Data Collection System (DCS) - a French system, ARGOS, designed to retrieve data from remote sensing platforms such as buoys.
4. Space Environment Monitor (SEM) - a three instrument multi-detector unit used to measure solar proton, alpha and electron particle flux.
5. Search and Rescue system (SAR) - a joint program designed to locate and identify downed aircraft and ships in distress.
6. Solar Backscatter Ultraviolet Instrument (SBUV) - monitors the ozone content in the earth's atmosphere.
7. Earth Radiation Budget Experiment (ERBE) - determines the radiation loss and gain to and from the planet. [Ref. 27]

e. Earth Resources Satellite (LANDSAT)

LANDSAT began flying in 1972 and was shifted from NOAA control to the commercial company EOSAT in 1984. Although not specifically designed for atmospheric/oceanographic sensing, it does provide useful data on ice and snow coverage. The current satellite is LANDSAT-5 launched 1 March 1984. The future of this system is in doubt because of drastic reductions in government funding. [Ref. 28]

Onboard sensors include:

1. Multi-spectral scanner (MSS) - a four channel visible and infrared scanner carried as a secondary sensor only in backup for the thematic mapper.
2. Thematic Mapper (TM) - a new instrument, first flown on LANDSAT-4, it is a seven channel mechanically scanned radiometer with a 30 meter resolution.

## 2. Foreign Programs

### a. Meteorological Satellite (METEOSAT)

The European Space Agency participates in the worldwide geostationary environmental satellite network with its preoperational meteorological satellite program. This satellite, similar to the U.S. GOES, operates at 0 degrees longitude. A standby spacecraft, currently METEOSAT-1, is located at 10 degrees west. A French Ariane 4 rocket launched METEOSAT-2 into orbit in June 1981. Although the design life of the satellite is three years, with the exception of the data collection package the satellite continues to operate to date. METEOSAT-1 is supporting the data collection mission. [Ref. 29] The primary instruments on all METEOSATs include:

1. Visible and Infrared Spin scan radiometer (VISSR) - three channel radiometer that provides day/night cloud cover, earth/cloud radiance, and temperature measurements.
2. Data Collection System (DCS) - up to 66 channel random access collection from buoys, balloons, and earth platforms.

### b. Indian National Satellite (INSAT)

India contributes to the worldwide geostationary system with its 3-axis stabilized multi-purpose INSAT, which operates at 72 degrees east longitude. INSAT is a preliminary design for the next series of U.S. GOES satellites. INSAT 1-B, built by Ford Aerospace and launched by the U.S. space shuttle on 30 August 1983, has a design life of seven years. It was scheduled to be augmented by INSAT 1-C in 1986 but with the shuttle grounded, unless India's request for a U.S. Delta launch is accommodated INSAT 1-B will continue to operate alone. [Ref. 30] Onboard sensors include:

1. Very High Resolution Radiometer (VHRR) - a two channel visible and infrared imaging system that provides day/night cloud cover, earth/cloud radiance, and temperature measurements.

2. Data Collection System (DCS) - random access collection from buoys, balloons, and earth platforms.

- c. Geostationary Meteorological Satellite

The Japanese GMS is sponsored by the Japan Meteorological Agency (JMA) and the National Space Development Agency of Japan (NASDA). An N-2 Japanese launch vehicle places the GMS satellites into orbit at 140 degrees east. Hughes Aircraft Company assists Japan in satellite construction. [Ref.31] GMS-3, launched in August 1984 with an 5 year design life, carries three onboard sensors:

1. Visible Infrared Spin Scan Radiometer (VISSR) - a two channel visible and infrared imaging system that provides day/night cloud cover, earth/cloud radiance, and temperature measurements.
2. Space Environment Monitor (SEM) - measures solar protons, electrons and alpha particles.
3. Data Collection System (DCS) - random access collection from buoys, balloons, and earth platforms.

- d. Marine Observation Satellite (MOS-1)

A new Japanese satellite, MOS-1, entered the polar orbiting environmental satellite family on 19 February 1987. Development of this satellite began in 1980 with launch originally scheduled for 1986.

The missions of MOS-1 are:

1. Establishment of fundamental technologies common to both marine and land observation satellites.
2. Observation of the state of the sea surface and atmosphere using visible, infrared and microwave radiometers and verification of the performance of these radiometers.

The satellite is sun-synchronous with an altitude of 909 kilometers and an inclination of 99.1 degrees.

MOS-1 has a three year design life.

MOS-1 is an indigenous Japanese satellite with Nippon Electric Company (NEC) as the prime

contractor. [Ref. 32] It carries three environmental sensors:

1. Multi-spectral electronic self-scanning radiometer (MESSR) - Four channels in the .5 - 1.1 micron range are used to make high resolution visible and infrared images and to detect sea surface color. Two identical systems are installed for increased reliability. In the normal mode, the MESSR has a swath width of 100 kilometers and a resolution of 50 meters, but by operating both systems simultaneously a swath of 220 kilometers is possible.
2. Visible and Thermal Infrared Radiometer (VTIR) - One visible and two infrared channels are used to detect sea surface temperature. Each channel has two detector elements to increase reliability. The swath width is 1500 kilometers.
3. Microwave Scanning Radiometer (MSR) - Two channels (23.8 and 31.4 GHz) are used to detect atmospheric water vapor and liquid water content.

e. **Systeme Probatoire d' Observation de la Terre (SPOT)**

France developed the highly successful land remote sensing satellite SPOT based on the proven LANDSAT concept. SPOT-1, launched by an Ariane rocket on 22 February 1986 into a 832 kilometer, 98.4 degree inclination orbit, provides visible imagery in stereo. Its main sensors are:

1. High Resolution Visible Range Instruments (HRV) - two systems which operate on four channels, one panchromatic and three multi-spectral. The panchromatic mode yields a resolution of 10 meters, while the multi-spectral mode offers a 20 meter resolution. [Ref. 33]

f. **Indian Stretched Rohini Satellite Series (SROSS)**

Rohini satellites are small (150 kilogram) indigenously launched experimental sensor platforms that often carry earth observation payloads [Ref. 30]. On 24 March 1987, a Rohini remote sensing satellite was destroyed when India's first Augmented Satellite Launch Vehicle (ASLV) failed to reach orbit. [Ref. 34]

### C. FUTURE SYSTEMS

#### 1. U.S. Systems

##### a. DMSP Block 5D-3

Originally planned for launch in 1993 on Titan II expendable launch vehicles, DMSP Block 5D-3 will probably not be orbited before the late 1990's. The current Block 5D-2 series has six remaining satellites, and these will be launched prior to starting the new series. The DMSP system is a launch-on-demand system, so new satellites will be launched as current ones fail. The next scheduled launch is S8, which will replace F7 (launched in 1983).

##### b. GOES - Next (I, J, K)

The requirements for the follow-on GOES satellite were defined in late 1980 and a request for proposal was issued in 1984. Ford Aerospace was awarded the contract to build the initial three spacecraft in the new series. Originally designed for launch by the shuttle, in early 1987 NASA directed Ford Aerospace to make the system compatible with either space shuttle or an expendable launch vehicle. On 1 May 1987 NOAA announced it was seeking commercial launch services for five GOES launches beginning in late 1989. [Ref. 35]

The most notable difference between GOES and GOES-Next is the spacecraft configuration. GOES-Next is a 3-axis stabilized spacecraft that will not be cylindrically shaped. There are several advantages to 3-axis stabilization:

1. It allows for better radiometric sensitivity (lower signal to noise ratio) which improves the quality of the data and makes it more usable.
2. Less time is required to scan an area, which gives the flexibility of interleaving full pictures and area scans.

3. The 3-axis platform is stable, which allows for better pointing accuracy.

GOES-I, J, and K will carry five instruments [Ref. 36, p. 100]:

1. Imager - a five channel imagery sensor
2. Infrared sounder - eighteen channels provide atmospheric sounding temperature and moisture profiles.
3. Space Environment Monitor (SEM) - same as current GOES
4. Data Collection System (DCS) - same as current GOES
5. Search and Rescue (SAR) - same as current GOES.

c. NOAA - Next (K, L, M)

Planned to meet polar orbiting environmental sensing needs for the 1990's, NOAA-Next was also originally designed for shuttle launch. Currently other options are being examined to ensure some method of launch will be available when the first satellite is ready to be orbited. The first three satellites in the series, NOAA K, L, and M, represent incremental improvements over the existing system. The instrument package will be basically the same, including the data collection system, search and rescue, and space environment monitor. Sensor improvements include [Ref. 36, p. 98]:

1. Advanced Very High Resolution Radiometer/3 (AVHRR/3) - will have six channels and a resolution of 1.1 km at the nadir and 4 km at the edge of scan.
2. Advanced Microwave Sounding Unit - A (AMSU-A) - will replace the SSU and MSU with 15 channels in the 23-90 GHz range to provide all weather temperature profiles with a 40 kilometer resolution.
3. Advanced Microwave Sounding Unit - B (AMSU-B) - will replace the MSU and SSU with five channels in the 90-183 GHz range to provide all weather atmospheric profiles with a 15 kilometer resolution.
4. High Resolution Infrared Radiation Sounder (HIRS/3) - same as HIRS/2 but with a broader spectrum (.2 - 15.0 microns) to

detect temperature and moisture profiles and earth radiation budget.

d. LANDSAT (6 and 7)

The first satellites of the series to be built for the Earth Observation Satellite Company (EOSAT), LANDSAT 6 and 7 will fly the Enhanced Thematic Mapper (ETM) to expand the spectral range and improve resolution. Launch was scheduled for the 1989-1992 timeframe, but may be delayed due to financial constraints. [Ref. 36, p. 101]

2. Joint U.S. / Foreign Programs

a. TOPEX/Poseidon

The U.S./French Ocean Topography Experiment will orbit an altimeter to map the topography of the ocean with a precision of two centimeters. Ocean currents will also be observed. A non-scanning radiometer will be onboard to provide the water vapor correction for the altimeter. Fairchild Space Company is the prime contractor and will provide the satellite and electronic monitoring controls. France will provide twenty percent of the total cost of the satellite, including launch on an Ariane rocket. Latest estimates predict launch of the spacecraft in 1992. TOPEX is designed for a three year mission, with a possible extension of up to two years. [Ref. 37]

b. Space Station/Polar Platforms

The free flying platforms that are an integral part of the NASA space station concept would be excellent remote sensing platforms. International participation in the program is being encouraged, and several countries have responded. ESA's proposed contribution to the project, COLUMBUS, includes plans for a separate European polar orbiting platform, a permanently attached pressurized lab module, a

man-tended free flyer, and a co-orbiting platform.  
[Ref. 38]

The space station and its associated platforms will be launched via the space shuttle. Because of this launch vehicle, the program will probably not be deployed by 1995 and many changes are bound to be made.

### 3. Foreign Programs

#### a. METEOSAT Operational Program (MOP)

The first two METEOSATS were testbed satellites for the prototype METEOSAT P-2 satellite. Originally scheduled for launch by an Ariane ELV in 1986, it is now scheduled for launch in early 1988. The operational system, MOP, is a series of three satellites scheduled for launch in late 1988, January 1990, and January 1991. [Ref. 39]

#### b. ESA Remote Sensing Satellite (ERS-1)

ERS-1 is an experimental polar orbiting spacecraft designed to establish, develop and exploit the coastal ocean and ice applications of remote sensing data and to increase scientific understanding of coastal zone and global processes. [Ref. 40] Dornier of West Germany won the prime contract for the satellite. The latest available projected launch date is 1990. ERS-1 will carry three primary instruments:

1. Active Microwave Instrument (AMI) - this instrument operates in two modes, as a synthetic aperture radar at 5.3 GHz and as a scatterometer at 5.3 GHz.
2. Radar Altimeter (RA) - will provide measurements of significant wave height, wind speed, and ice and current.
3. Laser Retroreflector (LRR) - provide accurate tracking and altimeter calibration.

In addition, two nationally provided sensors will be flown. These include an along track scanning radiometer (ATSR) from France and the United Kingdom

and a precise range and range rate experiment (PRARE) provided by West Germany. ERS-1 will be an experimental satellite similar to SEASAT with follow-on satellites projected. ERS-2 is scheduled for launch in 1993. Ultimately, formation of an operational global multi-satellite system is envisioned. [Ref. 39]

c. Radar Satellite (RADARSAT)

The Canadian government reviewed the plans for Canada's radar satellite in June 1987 and conditionally approved a scaled down version of RADARSAT. Originally the sensor suite was to have included a synthetic aperture radar, a scatterometer, and an optical imaging sensor. Current plans call for the launch of a single sensor, the synthetic aperture radar. The SAR will provide resolutions of 10 - 100 meters depending on the swath width. The normal operating mode will be a 100 kilometer swath with a 25 meter resolution. West Germany may provide a Modular Optoelectric Multispectral Scanner (MOMS) as part of the sensor suite. [Ref. 41]

Projected cost of the satellite is \$725 million (Canadian) with approximately \$390 million (Canadian) being funded by the United States and Great Britain. Approval is contingent upon U.S./U.K reaffirmation of funding commitment by the end of 1987. The U.S. portion of the cost covers launch services via the space shuttle, while the U.K. portion includes the spacecraft bus and possibly two instruments. U.S. officials are not optimistic about provision of shuttle launch services, so the fate of RADARSAT remains to be seen. If all goes well, launch is scheduled for 1994. [Ref. 41]

d. Japanese Earth Resource Satellite (JERS-1)

JERS-1 will be an active microwave sensing satellite carrying a synthetic aperture radar as its main sensor. It is designed for launch by a Japanese H-1 launch vehicle and will be placed into a 570 kilometer altitude with an inclination of 98 degrees. In addition to the SAR, a visible and near infrared radiometer (VNR) will be flown. The VNR replaces the MESSR and provides improved resolution and swath width. JERS-1 is scheduled for launch in 1991. [Ref. 41]

e. Marine Observation Satellite (MOS-2)

Feasibility studies for the second Japanese Marine Observation Satellite were conducted in 1985. Current plans call for a 1990 launch. [Ref. 39]

f. Indian Remote Sensing Satellite (IRS-1)

The Indian Remote Sensing Satellite series will be a series of semi-operational sun synchronous earth observation satellites launched by Soviet launch vehicles. The first of the series was scheduled to be launched in 1986, with follow-on satellites planned. Design life is three years. [Ref. 30] Onboard sensors include:

1. Linear Imaging Self Scanning Camera (LISS-1) - a four channel low (72 meter) resolution camera system.
2. Linear Imaging Self Scanning Camera (LISS-2) - two high resolution (36 meter) cameras, both with four channels.

D. SUMMARY

The above satellites represent an international recognition of the importance of satellite-sensed environmental data. Worldwide cooperation in the field of remote sensing allows for the free exchange of environmental data. Even so, there are problems with dependence on foreign systems. The next chapter will

identify deficiencies in the existing network of environmental satellites.

## **V. DEFICIENCIES IN SUPPORT FOR NAVY REQUIREMENTS**

### **A. INTRODUCTION**

The previous chapter examined current and future environmental satellite systems. A number of those satellites, although not specifically designed to sense oceanographic data, are able to fulfill some Navy requirements. To determine deficiencies in the available data, the specific data requirements must be identified in terms of resolution, measurement precision, measurement accuracy, data refresh period and timeliness.

Resolution is defined as the smallest area over which data about a particular phenomena can be averaged to meet requirements. Measurement accuracy is the allowable deviation from a value accepted as true and includes the errors in the measurement by the sensor system and in the reduction, processing, and distribution of data. Measurement precision is the degree of agreement between repeated measurements of the same quality. The refresh period is the average time interval between consecutive measurements of a given parameter for the same resolution. Timeliness is the elapsed time between completion of measurement of the required data set and delivery of the processed data to the user. [Ref. 43, p.150]

### **B. METHODOLOGY**

Each of the top ten oceanographic parameters identified in Chapter 2 will be matched with satellites and sensors that can provide that type of data. The data requirements will then be cross-referenced with the satellite capabilities to determine deficiencies.

For ease of reference, the prioritized list of parameters follows:

1. Sea Surface Temperature and Ocean Vertical Temperature Profile
2. Wind
3. Ocean Waves
4. Sea Ice
5. Atmospheric Temperature and Humidity Profile
6. Cloud cover
7. Ocean Current Profile, Near Shore and Ocean Currents
8. Ocean Optical
9. Visibility
10. Shallow Water Bathymetry

C. COMPARISONS OF AVAILABLE SENSORS TO DATA REQUIREMENTS

All Navy parameters require global coverage. In addition to that requirement, each of the top ten parameters will be examined in terms of the Navy/Marine Corps Oceanographic and Atmospheric Requirements dated 19 May 1987.

Sea Surface Temperature (SST) data requirements are:

Resolution: 1 km  
Accuracy : .2 degree Kelvin  
Precision : .1 degree Kelvin  
Refresh Period: 6 hours  
Timeliness: 3 hours

Current U.S. sensors providing SST information are the NOAA AVHRR and the GOES VAS. The AVHRR has a 1.1 km resolution and an accuracy of 1 degree Kelvin, but it is cloud limited. VAS resolution is .9 km in the visible range but only 7 or 14 km in the infrared region. The VAS provides coverage every half hour from

its geostationary vantage point. [Ref. 36] None of the above sensors meet the requirements listed.

Ocean Vertical temperature requirements are not listed here because the technology to directly detect vertical temperature profiles from space does not currently exist: "There is no way to observe this parameter from space, since the ocean is opaque to electromagnetic radiation. We must use in-situ observations." [Ref. 44, p. 342]

Although not specifically stated, the requirements for wind speed and direction are aimed more toward marine surface winds than winds aloft. The requirements are:

Resolution: 10 kilometers

Accuracy: 2 meters/second, 10 degrees

Precision: 1 meter/second, 5 degrees

Refresh Period: 3 hours

Timeliness: 15 minutes

The GOES VAS can be used to derive both wind speed and direction at cloud levels by watching cloud movements.

These data are available when clouds occur, and are limited by the difficulty of cloud height specification. Current U.S. sensors are not capable of directly determining surface wind direction but the technology does exist and was proven on the SEASAT scatterometer.

Wind speed can be determined by the DMSP SSM/I and the GEOSAT ALT. The SSM/I resolution (55 km) does not meet the requirement. The ALT does meet the resolution requirement, but it cannot meet the refresh period or the timeliness requirements. Because it is not directly downlinked to operational processing

sites, the information can take as long as two weeks to be distributed. [Ref.45]

Several parameters are desired on ocean waves. First, the significant wave height ( $H_{1/3}$ ) is needed. Significant wave height requirements are:

Resolution: 5 kilometers  
Accuracy: +.5 meters to +10%  
Precision: +.5 meters to +10%  
Refresh Period: 3 hours  
Timeliness: 30 minutes

The GEOSAT ALT is the only U.S. sensor in orbit that can detect significant wave height, and it cannot meet the resolution requirements because of its limited swath width. [Ref. 36] The second parameter required for ocean waves is the wave spectrum (amplitude, wavelength and direction). Requirements are:

Resolution: 5 kilometers  
Accuracy: +.5 meter to +10% (amplitude)  
+ 5% (wavelength)  
+10 degrees (direction)  
Precision: same as accuracy  
Refresh Period: 3 hours  
Timeliness: 30 minutes

No current U.S. sensor can provide this data. The SAR on SEASAT was able to provide information on wavelength and direction, so the technology does exist.

Sea Ice parameters are separated into three distinct areas, extent, thickness and age.

Measurement requirements are:

Resolution: 25 kilometers  
Accuracy: 10 % ; +.5 meters; 6 months  
Precision: 5 %; .25 meters; 6 months  
Refresh Period: 24 hours  
Timeliness: 12 hours

The DMSP SSM/I provides data on extent (25 km resolution) and age, and the OLS can determine ice/no ice in the cloud free areas [Ref. 6]. The extent of the ice is detected by the GEOSAT ALT and the LANDSAT MSS and TM. The French SPOT satellite can also provide coverage information.

The atmospheric temperature profile requirements are:

Resolution: 10 kilometers (horizontal)  
30 meters (vertical)  
Accuracy: +10%  
Precision: 1 degree Kelvin  
Refresh Period: 6 hours  
Timeliness: 30 minutes

Current U.S. sensors providing this type of information include the GOES VAS, NOAA HIRS and MSU, and DMSP SSM/T. The VAS is cloud limited and only operates between 50 degrees north and south latitudes. For an accuracy of +2 degrees Kelvin, the resolution is only 30-100 km. [Ref. Greaves, p. 171] The HIRS has a 14 km resolution and the MSU has a 109 km resolution, but data processing requirements reduce resolution to 140 km. The SSM/T has a 207 km resolution with a precision of .1 degree Kelvin and an accuracy of 2.5 - 3.0 degrees Kelvin. [Ref. 6, p. A-12]

The atmospheric humidity profile requirements are:

Resolution: 5 kilometers (horizontal)  
30 meters (vertical)

Accuracy: +10 %

Precision: +.3 grams/cubic meter

Refresh Period: 1 hour

Timeliness: 30 minutes

U.S. sensors retrieving this data include the NOAA HIRS and the DMSP SSM/T. HIRS does not meet the resolution requirements. The SSM/T has a 40 km horizontal resolution and a 2 km vertical resolution. Its accuracy is 2.5 Kg/square meter. [Ref. 36]

Cloud coverage data requirements are:

Resolution: .5 kilometers

Accuracy: +.5 %

Precision: +5 %

Refresh period: On call

Timeliness: 4.8 minutes

Many satellites look at cloud coverage, including the GOES VAS, DMSP OLS, NOAA AVHRR and the foreign geostationary satellites GMS, INSAT, and METEOSAT. OLS can almost meet the resolution requirements using its fine mode (.55 km resolution). Other satellites do not have the high resolution required.

Three types of currents are of interest to the Navy: near shore currents, ocean surface currents and ocean current profile. Requirements for near shore currents are:

Resolution: 10 meters

Accuracy: +.1 meter/second, +10 degrees

Precision: same as accuracy

Refresh period: 3 hours

Timeliness: 30 minutes

The high resolution is required to support naval warfare areas like amphibious warfare, special operations and logistics. No existing sensor can meet that requirement.

For ocean surface currents, the requirements are less stringent:

Resolution: 10 kilometers

Accuracy: +.1 meter/second, 10 degrees

Precision: same as accuracy

Refresh period: 12 hours

Timeliness: 3 hours

The GEOSAT ALT, GOES VAS, LANDSAT TM all provide data on ocean currents. The OLS on DMSP can detect major currents (direction only) and it meets the all the above requirements but it is cloud limited.

The ocean current profile, like the ocean vertical temperature profile, is not detectable by existing sensor technology.

Ocean optical profiles (extinction and scattering) are not specified by requirements such as resolution, precision, etc. Optical imagers provide partial information on the extinction profile, but no sensor currently provides information on the scattering profile.

Requirements for visibility are:

Resolution: 5 kilometers

Accuracy: +.5 kilometers

Precision: N/A

Refresh period: 6 hours

Timeliness: 15 minutes

Visibility information is obtained from the NOAA AVHRR and the GOES VAS. AVHRR resolutions (1.1 kilometer) meet that requirement as does the resolution on VAS (.9 kilometer in the visible and 7 or 14 kilometer in the infrared).

Shallow water bathymetry is the ability to detect the ocean bottom topography. Requirements vary with the area being surveyed and are specified on an case-by-case basis.

#### D. SUMMARY

Two factors are obvious from the above comparisons. First, the ability to detect oceanographic parameters is limited. Of the 10 top priority parameters, six are specifically ocean related. Of those six, the following are not capable of being detected by existing satellites:

1. Ocean vertical temperature profile.
2. Wind direction
3. Wave spectra (amplitude, wavelength and direction)
4. Sea ice thickness
5. Near shore currents and ocean current profile
6. Ocean optical profiles
7. Shallow water bathymetry

Second, the timeliness/refresh period requirements almost demand a system of satellites as opposed to just one. The next chapter will examine the ability of NROSS to fill some of the gaps in the existing coverage.

## VI. THE NAVY REMOTE OCEAN SENSING SYSTEM (NROSS)

### A. INTRODUCTION

The Navy has sponsored investigations of the microwave radiometric properties of the ocean and atmosphere since the early fifties. Starting with basic research into properties of the sea surface, the Navy progressed to planning, developing and using satellites. The first attempt at developing an oceanographic satellite was the Remote Ocean Surface Measurement System (ROMS). Although ROMS was not built, the technology for it directly contributed to subsequent systems. This chapter will examine the most recent Navy initiative into remote sensing of the ocean from space, the Navy Remote Ocean Sensing System (NROSS).

### B. NROSS MISSION AND PARTICIPANTS

NROSS was originally conceived following the demise of NOSS to become the polar orbiting oceanographic satellite system of the 1980's. It will use existing sensor technology, a NOAA/DMSP satellite bus, the established DMSP ground sites (for housekeeping and data relay), and the soon to be operational TESS 3 (for direct read out to the fleet). It will be an economically feasible satellite designed to meet operational requirements using existing technology and support systems. The mission of NROSS is "the operation of a remote ocean sensing system that will routinely supply specific global oceanographic data under all weather conditions to military and civilian operational users." [Ref. 46] See Figure 6.1.

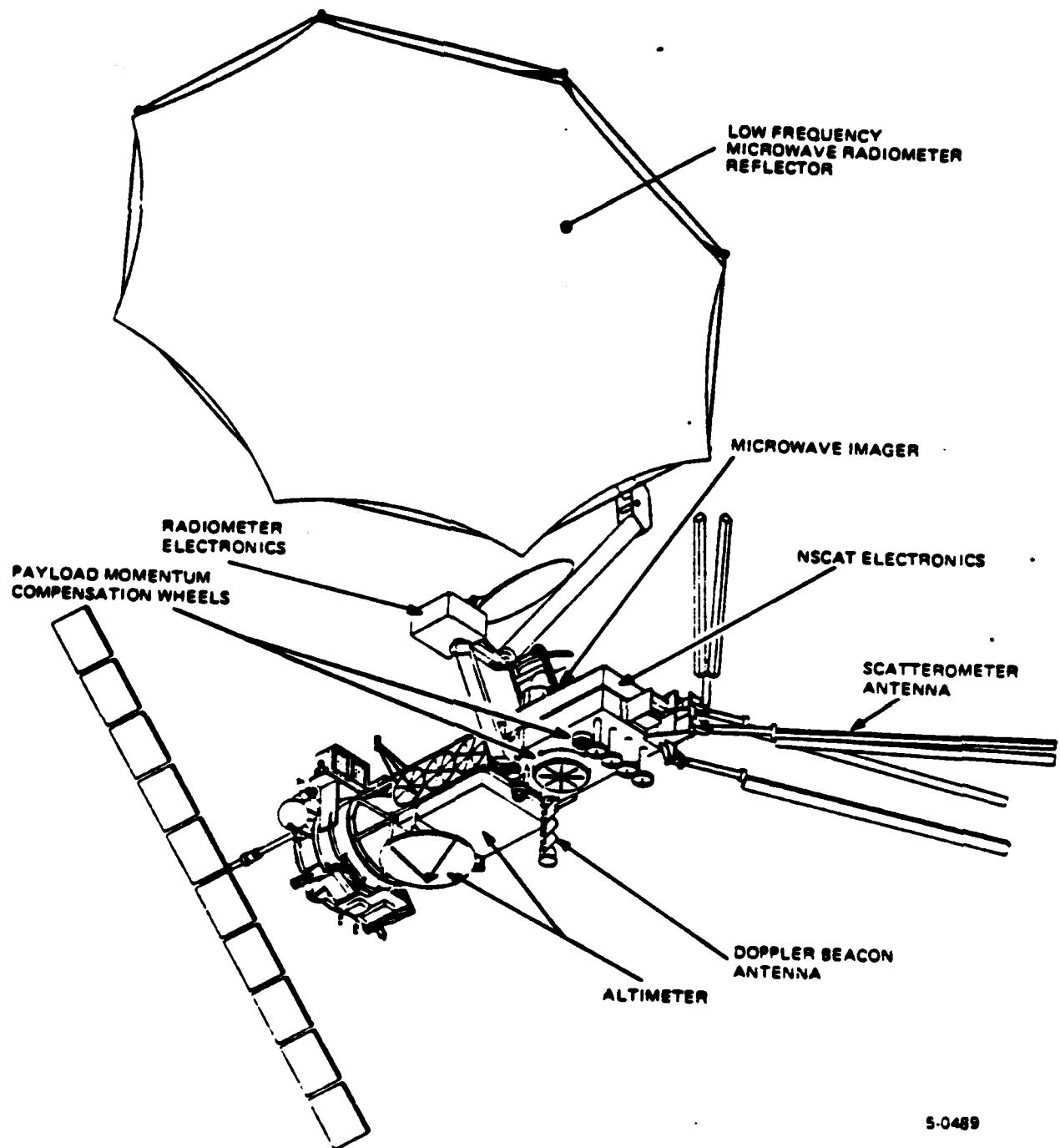


FIGURE 6.1  
NAVY REMOTE OCEAN SENSING SYSTEM (NROSS)

[Ref. 46, p. 2-5]

Although NROSS is a completely Navy managed program, the Air Force, NASA, and NOAA are also involved in planning and use of the satellite. A Combined Memorandum of Agreement delineates the responsibilities of each participant. The Air Force is providing launch services from Vandenberg Air Force Base; the Titan II launch booster; telemetry, tracking and control (TT&C) and data relay services; and command and control. NASA has responsibility for development of the scatterometer hardware and its associated research algorithms for data interpretation. NOAA is acting as the representative of the civil operational community and will assist in algorithm development for the sensors. It will also maintain the data archives. [Ref. 47]

### C. NROSS HISTORY

#### 1. The Acquisition Process

The history of the NROSS program may best be examined by looking at the acquisition process. There are four main phases in the acquisition process: concept exploration, demonstration and validation, full scale development and full scale production. Prior to the concept exploration phase is a period called pre-program initiation, which is the initial part of the acquisition process. Each phase has a required milestone at which decisions are made to proceed with the next phase. [Ref. 48]

##### a. Program initiation

In March 1981, the Assistant Secretary of the Navy for Research, Engineering and Systems (ASN (RE&S)) under his purview as the Navy Acquisition Executive for research, development, test and evaluation (RDT&E) instructed the Director, Research, Development and Acquisition (OP-098) to "examine

affordable options to satisfy Navy requirements for satellite measurements of oceanographic parameters in fiscal year 1983 and beyond." [Ref. 49] This request started the NROSS pre-program initiation phase.

During this phase, a mission area analysis is conducted and a tentative operational requirement is developed. Preparations are made for a milestone 0 review. At this review, the decision is made to initiate the concept exploration phase, the program is assigned an acquisition category (ACAT) and a program element number to begin the funding process [Ref. 48]. With the NOSS experience still fresh, the Director, Naval Oceanography Division (OP-952) quickly responded with the proposal for NROSS. The concept was briefed to the Director, Research, Development and Acquisition (OP-098) in June 1981, and the Chief of Naval Operations was briefed in August 1982. [Ref. 49]

In January 1983, ASN (RE&S) declared NROSS to be an ACAT IIS program. An ACAT IIS designation indicates that the total program costs are expected to exceed \$100 million for RDT&E and/or \$500 million for procurement (in 1980 dollars) or the program is of special interest to the Secretary of the Navy (SECNAV). Additionally, the designation of the acquisition category was one of the steps to achieving milestone 0. Approval to proceed beyond milestone 0 came in May 1983 when NROSS was funded as a "new start" program for fiscal year 1985. [Ref. 49]

#### b. Concept Exploration

The concept exploration phase follows milestone 0, and includes the examination and selection of the most promising concept to proceed to the next phase. The program manager is named and a program management office (PMO) is established. An acquisition strategy is created, and two documents are

prepared for the milestone I review: the draft Test and Evaluation Master Plan (TEMP) and the Navy Decision Coordinating Paper (NDCP). The NROSS program was identified as an oceanography initiative in July 1984 and continued funding support was directed for fiscal year 1986 and beyond.

On 24 May 1984 SECNAV signed the Combined Memorandum of Agreement (MOA) between the Department of the Navy and the three other participating agencies concerning the development and operation of NROSS. This was a significant event because the Navy could not afford to provide sole funding for NROSS. Later that month on 29 May, the NDCP was approved and progress beyond milestone I to the demonstration and validation phase of the acquisition process began.

c. Demonstration and Validation

During the demonstration and validation phase, more refined analysis is done to demonstrate the technology and critical issues are resolved. Specifications are written, the TEMP is approved, and the NDCP and the acquisition strategy are updated.

[Ref. 48]

In December 1985 ASN (RE&S) directed that NROSS be a competitive procurement rather than sole source in accordance with the Competition in Contracting Act of 1984. This encouraged other companies to respond to the NROSS request for proposal. A fixed price type contract was specified on 21 March 1986 and the Navy was directed to identify funds in the program objective memorandum (POM) for 1988 to purchase one satellite. [Ref. 49]

d. Milestone II Review

The Milestone II review is critical in any system acquisition, but especially in the case of a satellite program. For a satellite procurement,

successful completion of this review constitutes approval to develop and build the first satellite. In preparation for the milestone II Navy Program Decision Meeting (NPDM) on 18 November 1986 several documents were prepared. One of these, the updated NDCP, discussed the subject of NROSS affordability:

NROSS program cost estimates...are dependent on the source selection decision for the competitive procurement of the spacecraft and subsystems...and will not be announced until the NPDM for Milestone II. [Ref. 49]

In fact, at the NPDM a cost overrun of \$150 million was identified and ASN (RE&S) instructed the Navy to eliminate the excess.

e. NROSS Cancelled

The Navy responded with three options, which were presented on 11 December 1986:

- 1) Find the money to continue the program.
- 2) Delete the low frequency microwave radiometer (LFMR) from the sensor suite and continue the program at reduced cost.
- 3) Cancel the program. [Ref. 50]

After reviewing the choices, ASN (RE&S) decided to cancel the program. As a Milestone II decision requires SECNAV approval, on 15 December 1986 the decision was briefed to SECNAV, who concurred.

NROSS, like its predecessor NOSS, was cancelled.

2. Reaction to NROSS Cancellation

The cancellation of NROSS received negative publicity in several defense publications (Defense News, Navy Times and Aviation Week to name a few) and the other participants in the program expressed their displeasure. NASA Chief James Fletcher, in a memorandum to Deputy Secretary of Defense William Taft IV, stated:

The assumption that there would be an NROSS has been a critical factor in developing our own plans for conducting oceanographic research from space. The cancellation of NROSS would result in a substantial loss of important oceanographic data. [Ref. 50]

In February 1987, SECNAV discussed an alternative plan with the Secretary of the Air Force. NROSS sensors would be incorporated into the Air Force Defense Meteorological Satellite Program (DMSP) and the Navy would pay the engineering costs for the implementation. This plan did not include the LFMR. [Ref. 51]

### 3. NROSS Revived

Meanwhile, efforts were continuing to get the NROSS program reinstated. The Office of Naval Research Oceanographic Division submitted a proposal to SECNAV identifying money from a research and development account that could be used to restart the program. In late February, SECNAV agreed to reconsider his decision, and on 30 March 1987 NROSS was reborn [Ref. 52]. None of the instruments were eliminated from the original sensor suite but cost reductions were stipulated. The reduced costs were to be achieved by using a capped development environment [Ref. 53].

#### a. Guidelines for Restart

In a 10 April 1987 memorandum to CNO, SECNAV directed that the resuscitated program follow several guidelines:

- 1) The restart was for the acquisition of a single spacecraft.
- 2) NROSS was upgraded to ACAT I with a cost cap of \$335 million.
- 3) The 1985 Combined MOA would be adhered to.
- 4) All original capabilities, especially the LFMR, would be provided.
- 5) The NROSS PMO would be at the Space and Naval Warfare Systems Command (SPAWAR). [Ref. 54]

The PMO had been decimated when NROSS was cancelled, with only the Program Manager remaining. All outyear funding for NROSS was removed from the

Five Year Defense Plan (1988-1993). When the program was restarted in March 1987, minimal 1987 fiscal year funding remained, as most funds had been re-allocated when the program was cancelled. [Ref. 53]

b. Current Status

As of September 1987, the PMO is beginning to recoup its losses. The Navy Milestone II Decision Coordinating Meeting is scheduled for October to be followed by a Defense Acquisition Board (DAB) Review in November. If all goes well, the Defense Acquisition Executive will receive the NROSS Decision Coordinating Paper for approval before the end of this year. Contract award is scheduled for mid-1988, and spacecraft delivery is expected approximately 42 months later. Pending adequate funding, latest launch estimates put NROSS in orbit by early 1992. [Ref. 53]

D. NROSS INSTRUMENTATION

NROSS will carry a sensor suite of four microwave instruments: a scatterometer (NSCAT), an altimeter (ALT), a low frequency microwave radiometer (LFMR) and a special sensor microwave imager (SSM/I). Use of the microwave region will provide NROSS with an all-weather capability. With the exception of the LFMR, the selected sensors are all derived from proven instruments which have been successfully deployed in space. [Ref. 46] See Table 6.1.

The altimeter is an active instrument similar to the one flown on SEASAT and currently flying on GEOSAT. The NROSS altimeter will reflect the improvements learned from the GEOSAT mission.

The one meter diameter antenna on ALT will operate at 13.6 GHz and measure the area directly beneath the satellite. It will measure information on significant wave height, ocean topography, wind speed, and ocean

<u>NAME</u>	<u>SWATH WIDTH</u>	<u>FREQUENCY</u>	<u>MEASURED PARAMETERS</u>
ALTIMETER (ALT)	10 KM ON NADIR TRACK	13.6 GHZ	SEA STATE, OCEAN SURFACE TOPOGRAPHY, ICE SHEET BOUNDARIES SURFACE WIND SPEED AT NADIR, AND OCEAN CURRENTS.
SCATTEROMETER (NSCAT)	700 KM TO BOTH SIDES OF NADIR TRACK	13.995 GHZ	SURFACE WIND SPEED AND DIRECTION.
SPECIAL SENSOR MICROWAVE IMAGER (SSMI)	1400 KM	19.35, 22.235, 37, AND 85.5 GHZ	SURFACE WIND SPEED, SURFACE TEMPERATURE, SEA ICE COVER (CONCENTRATION AND AGE), ATMOSPHERIC WATER VAPOR, AND LIQUID WATER.
LOW FREQUENCY MICROWAVE RADIOMETER (LFMR)	1400 KM	5.2 AND 10.4 GHZ	SEA SURFACE TEMPERATURE.

[Refs. 6 & 46]

fronts and eddies. It will be able to detect significant wave height to an accuracy of +.5 meters or 10 % with a 25 km resolution, and it will be able to detect altitude of the spacecraft to within 25 cm. [Ref. 49]

NASA is developing and building the second active sensor, the scatterometer. It is based on the 1978 SEASAT scatterometer. NSCAT will fly six fan beam antennas vice the four flown on SEASAT. It will operate at 13.995 GHz and provide information on global wind speed (+ 2.0 m/s accuracy at 25 km resolution) and direction (within 20 degrees accuracy at 25 km resolution). The additional two antennas will help resolve the directional ambiguities encountered in the SEASAT data. [Ref. 55]

The two remaining NROSS instruments, the SSM/I and the LFMR, are passive radiometers with rotating antennas. A radiometer is an instrument that measures the upwelling radiation from the earth's surface.

The SSM/I on NROSS will have a parabolic reflecting antenna that will operate at four frequencies: 19.35, 22.235, 37.0 and 85.5 GHz. SSM/I measurements are all at a 25 km resolution and can provide information on ocean surface wind speeds, sea ice conditions (ice edge to an accuracy of +12.5 km), precipitation intensity (to within 5.0 mm/hour), water content (both liquid water, at an accuracy of 2.0 kg/square meter and water vapor, at an accuracy of .1 kg/square meter) and soil moisture. The sensor is identical to the one currently flying on DMSP F8. Data from that instrument will be used to test and modify existing algorithms and the sensor will act as a testbed for the SSM/I to be launched on NROSS. [Ref.49]

The NROSS instrument with the highest technological risk is the LFMR. A new design, it will carry a very

large antenna (approximately six meters in diameter) to achieve desired resolutions. As mentioned earlier, the LFMR will have a rotating antenna. This may cause problems with spacecraft stability and could have an adverse affect on pointing accuracy, so careful consideration is being given to the LFMR design.

[Ref. 56]

The LFMR frequency selection is extremely important. The frequency must be sensitive to sea surface temperature and not to other environmental parameters. The most promising frequency range appears to be from 4 - 6 GHz, with warm water sensitivity being better at 6 - 10 GHz. Additionally, use of both horizontal and vertical polarizations enables better refinement of data. For the NROSS LFMR, two frequencies (5.2 and 10.4 GHz) will be sampled using dual polarization. The LFMR will retrieve data on brightness temperature to an accuracy of 1.0 degree Celsius with sufficient resolution to allow creation of global synoptic maps of sea surface temperature. [Ref. 56]

#### E. SUMMARY

NROSS, when launched, will allow real time oceanographic data distribution to the fleet. Its sensors were selected to provide the most oceanographic data for the least technological risk and cost. No single sensor can provide all of the required data, so NROSS will fly a suite of instruments to cover existing gaps. The next chapter will look to the future of NROSS and Navy abilities to meet their requirements for oceanographic data from space.

## VII. SUMMARY: A LOOK TO THE FUTURE

### A. INTRODUCTION

NROSS is a valuable force multiplier, but it cannot serve the Navy well if it remains on the ground. It was cancelled once. What will prevent it from encountering the same fate again? The austere budget of the early 1980's is even more limited today due to debt reduction requirements. Satellites are becoming more expensive. To delay in launching NROSS any longer risks losing the Navy oceanographic sensing capability altogether. NROSS is even more valuable today than when it was first conceived and the Navy needs it now.

### B. A NEW ENVIRONMENT

The U.S. Navy is facing a more formidable threat, especially from the new Soviet attack submarines. The Akula, Mike and Sierra SSN's are more quiet than anticipated and consequently more difficult to detect. As enemy submarines become less noisy, reliance on acoustic detection methods will become obsolete. The trend is shifting from acoustic detection methods to non-acoustic methods, and remote sensing from space can assist in the transition. Adm. Carlisle A. H. Trost, Chief of Naval Operations, has made ASW the Navy's number one warfighting priority. He believes that "space-based systems would permit us to know the ocean environment, including acoustic and radio propagation, with certainty and totality." [Ref. 57] By providing a global data base over time, it may be possible to compare anomalies in the ocean structure to historical profiles to help determine their cause.

The ability of the U.S. and its allies to place satellites into orbit was severely hampered by the grounding of the space shuttle and the Ariane expendable launch vehicle. Although both systems should be flying within the next year, launch schedules for all payloads have been delayed. Priority satellites will be launched first, and this could postpone the launch of environmental satellites even further. Planned oceanographic systems could help the Navy to meet its requirements, but their launch dates are not definite.

The requirements specified in the Satellite Measurement of Oceanographic Parameters Operational Requirement (SMOP/OR W0527-0S) back in 1977 have not been met and are still valid. Oceanographic parameters identified in Chapter II remain critical to naval warfare requirements and some have even increased in importance with the advent of new weapons systems.

#### C. COST FACTORS

The cost cap of \$335 million placed on NROSS when it was revived may appear to some to be an extravagant amount, but it is difficult to quantify the benefits NROSS could provide. A cost effectiveness study conducted in June 1987 compared the cost of NROSS to current collection methods (ships and buoys, and P-3 Orion aircraft with environmental sensors). Three transits were chosen: A Pacific Ocean Battle Group crossing, an Atlantic Ocean Battle Group Transit, and an Atlantic Ocean convoy transit.

NROSS cost to provide complete support for the three tracks was \$2.951 million. The cost of using P-3 aircraft for the same three tracks was \$5.06 million. Using existing ships and buoy data, the cost was an extravagant \$29.49 million for only 75% of the data

NROSS could provide [Ref. 58]. Clearly, NROSS is more cost effective than existing systems. Use of current satellites would be less expensive, but as shown in Chapter V these systems are not capable of meeting Navy tactical requirements.

#### D. SUMMARY

NROSS is a valuable force multiplier, but the fleet operators are not convinced of the need for an oceanographic system. What can NROSS do for them? At the very least, it will provide the warfighting Navy with previously unavailable information. NROSS could give a U.S. submarine the ability to avoid detection more easily; it could allow more accurate placement of in-situ acoustic detectors and limit time wasted in search areas with unfavorable oceanographic conditions; it could aid a battle group in its ability to transit covertly and it could allow more effective use of ASW aircraft [Ref. 59, p. 113].

NROSS is a valid concept for an operational oceanographic satellite to satisfy Navy warfare requirements for environmental data. Its sensor suite, in concert with existing systems, will provide the first opportunity for global near-continuous coverage of the world's oceans.

## LIST OF REFERENCES

1. Draft Navy Remote Ocean Sensing System Test and Evaluation Master Plan (TEMP), Number 968, NROSS Program Management Office (PMW 142-3), dated 26 June 1986.
2. Watkins, James D., "Space Control is Sea Control," remarks presented at the inauguration of the Naval Space Command, 1 October 1983.
3. Dictionary of Military Terms: JCS Publication 1. U.S. Government Printing Office, 1977.
4. Honhart, David C., "Requirements for Space-Sensed Oceanographic Data," pp. 142-145 in Recent Advances in Civil Space Remote Sensing, The International Society for Optical Engineering, 1984.
5. McGoldrick, L. F., "Remote Sensing for Oceanography: Past, Present, Future," p. 1, in Frontiers of Remote Sensing of the Oceans and Troposphere from Air and Space Platforms, NASA Conference Publication 2303, 1984.
6. Brown, Donald N. and McCandless, S. Walter, Planning and Reference Guide for Naval Oceanography from Space (For Official Use Only), November 1986.
7. Office of Naval Research Space Oceanography Group, "Navy and Marine Corps Oceanographic and Atmospheric Requirements from Space," chart dated 19 May 1987.
8. Maul, G. A., Introduction to Satellite Oceanography, Martinus Nijhoff, 1985.
9. Haas, I. S. and Shapiro, R., "The Nimbus Satellite System: Remote Sensing R&D Platform of the 1970's," pp. 71-95 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
10. Horan, J. J., "Space Instruments for Oceanography," pp. 239-248 in A Collection of Technical Papers--Satellite Applications to

Marine Technology, American Institute of  
Aeronautics and Astronautics, Inc., 1977.

11. Montgomery, D. R. and Wolff, Paul, "Seasat-A and the Commercial Ocean Community," pp. 276-283 in A Collection of Technical Papers--Satellite Applications to Marine Technology, American Institute of Aeronautics and Astronautics, Inc., 1977.
12. Elachi, C., Cimino, J., and Granger, J., "Remote Sensing of the Earth with Spaceborne Imaging Radars," pp. 639-683 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
13. Apel, John R., "A Survey of Some Recent Scientific results from the Seasat Altimeter," pp. 326-334 in Satellite Microwave Remote Sensing, Ellis Horwood, Ltd., 1983.
14. Pierson, Willard J., "Winds over the Oceans as measured by the Scatterometer on SEASAT," pp. 563-571 in Oceanography from Space, Plenum Publishing Corp., 1981.
15. Taylor, P. K., "The Scanning multichannel microwave radiometer--an assessment," pp. 463-477 in Satellite Microwave Remote Sensing, Ellis Horwood, Ltd., 1983.
16. Gower, J. F., "A Review of SEASAT," pp. 14-44 in Satellite Microwave Remote Sensing, Ellis Horwood, Ltd., 1983.
17. Born, G. H., Laine, D. B., and Rygh, P.J., "A Survey of the Goals and Accomplishments of the SEASAT Mission," pp. 3-14 in Oceanography from Space, Plenum Publishing Corp., 1981.
18. Bender, Eric, "A National Oceanic Satellite System," Sea Technology, April 1980, pp. 18-22.
19. "Defense Forges Ahead in Budget Sweepstakes," Sea Technology, March 1980, pp. 18-22.
20. "NOSS sensors scheduled to be included in Defense Satellites," Sea Technology, August 1981, pp. 64-65.

21. Barrett, E. C., and Curtis, L. F., Introduction to Environmental Remote Sensing, Chapman and Hall, 1982.
22. National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration, Aeronautics and Space Report of the President: 1985 Activities, U.S. Government Printing Office, 1985.
23. Gomberg, Louis and McElroy, S. M., "Remote Sensing of the Earth with the Defense Meteorological Satellite," pp. 96-122 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
24. Meyer, Walter D., "The Defense Meteorological Satellite Program: a Review of its Impact," pp. 129-149 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
25. Snow, Rick and Higgins, John, "The Tactical Environmental Support System TESS(3)," presented at the Naval Postgraduate School MR4520 Advanced Remote Sensing Course, 4 June 1987.
26. Greaves, J. R., and Shenk, W. E., "The Development of the Geosynchronous Weather Satellite System," pp. 150-181 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
27. Schnapf, Abraham, "The TIROS Meteorological Satellites--Twenty five years: 1960-1985," pp. 51-70 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
28. Nowle, Edward W., "LANDSAT D and D'--the Operational Phase of Land Remote Sensing from Space," pp. 349-370 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American

Institute of Aeronautics and Astronautics,  
Inc., 1985.

29. Honvaut, Claude, "The Operational Meteosat Program," pp. 483-492 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
30. Rajan, Y. S., "Remote Sensing Activities in India - Past, Present and Future," pp. 621-636 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
31. Homma, Masanori, and others, "Geostationary Meteorological Satellite System in Japan," pp. 570-588 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
32. Kusanagi, M., and others, "Marine Observation Satellite MOS-1," pp. 589-605 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
33. Courtois, Michel and Weill, Gilbert, "The SPOT Satellite System," pp. 493-523 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
34. "Back-to-Back launch failures," Aerospace America, May 1987, p. 1.
35. Eberhart, J., "Getting into orbit - the non-NASA way," Science News, 23 May 1987, p. 326.
36. National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration, Space-Based Remote Sensing of the Earth and its Atmosphere: A Report to Congress, Government Printing Office, April 1986.

37. Baker, Simon, "France Rides High," Space Markets, Summer 1987, pp. 73-77.
38. Owen, Kenneth, "Partners Haggle over Space Station," Aerospace America, May 1987, p. 10.
39. "Current Earth Observation Programmes - A worldwide Overview," Earth Observation Quarterly, June 1987, pp. 1-3.
40. Duchossois, G., "ERS-1: Mission Objectives and System Description," pp. 536-551 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
41. "Canada approves development of scaled back RADARSAT," Aviation Week and Space Technology, 13 July 1987, pp. 51-53.
42. Horikawa, Yasushi, "Studies on Japanese Earth Resources Satellite," pp. 606-620 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
43. Sherman, John W., "Civil Oceanic Remote Sensing Needs," pp. 149-154 in Recent Advances in Civil Space Remote Sensing, The International Society for Optical Engineering, 1984.
44. Suomi, Verner E., "Some possibilities on an Observing System for the World Climate Program," pp. 305-346 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
45. Frain, W.E. and others, "The Navy GEOSAT Mission Radar Altimeter Satellite Program," pp. 440-463 in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors, Systems, and Applications, Volume 97, American Institute of Aeronautics and Astronautics, Inc., 1985.
46. Navy Remote Ocean Sensing System: Mission Description (Final Draft), Naval Research Lab, June 1985.

47. Navy Remote Ocean Sensing System (NROSS)  
Memorandum of Agreement (MOA), 2 August 1985.
48. Navy Program Manager's Guide, 1987.
49. Chief of Naval Operations Letter: Serial 943D  
to Space and Naval Warfare Systems Command,  
Subject: Navy Remote Ocean Sensing System  
(NROSS) Navy Decision Coordinating Paper, 10  
Nov 1986.
50. Eisenstadt, Steven, "Navy Scraps Space Plan's  
Cornerstone," Defense News, 22 December 1986,  
p. 1.
51. Eisenstadt, Steven, "Lehman Seeks Air Force  
Help in Satellite Program," Navy Times, 23  
February 1987.
52. Eisenstadt, Steven, "Lehman Reverses Himself,  
Rethinks Satellite Cancellation Decision,"  
Navy Times, 20 April 1987.
53. Holben, Neil, Phone conversation 17 September  
1987 concerning NROSS program status.
54. Space and Naval Warfare Systems Command (SPAWAR  
87-48) Navy Remote Sensing System (NROSS) Draft  
Acquisition Plan, 29 June 1987.
55. Li, F. and others, "NROSS Scatterometer - An  
Instrument for Global Oceanic Wind  
Observations," pp. 193-197 in Recent Advances  
in Civil Space Remote Sensing. The  
International Society for Optical Engineering,  
1984.
56. Hollinger, J. P. and Lo, R. C., "Low Frequency  
Microwave Radiometer for NROSS," pp. 199-207 in  
Recent Advances in Civil Space Remote Sensing.  
The International Society for Optical  
Engineering, 1984.
57. Trost, Carlisle A. H., "The Potential of Space  
and Anti-Submarine Warfare," Defense Issues,  
Volume 12, Number 41, 1987.
58. Office of Naval Research letter: Subject:  
Navy Remote Ocean Sensing System (NROSS)  
Warfighting Benefit Study (Cost Effectiveness  
Subsection), 30 June 1987.

59. Honhart, David C., "NROSS: A New ASW Dimension," U.S. Naval Institute Proceedings, September 1987, pp. 111-113.

## INITIAL DISTRIBUTION LIST

	No. copies
1. Defense Technical Information Center Cameron Station Alexandria, Va. 22304-6145	2
2. Library, Code 0142 Naval Postgraduate School Monterey, Ca. 93943-5002	2
3. Commander Naval Space Command Attn: Code N3 Dahlgren, Va. 22448	2
4. Commander United States Space Command Attn: Technical Library Peterson AFB, Co. 80914	2
5. LT. Cheryl L. Spohnholtz, USN 1316 Hound Chase Circle Pensacola, Fla. 32514	3
6. Commanding Officer Fleet Numerical Oceanographic Center Attn: Library Monterey, Ca. 93943-5006	1
7. Commanding Officer Navy Environmental Prediction Research Facilities Attn: Library Monterey, Ca. 93943-5006	1
8. Commanding Officer Navy Environmental Prediction Research Facilities Attn: Dr. Andreas K. Goroch Monterey, Ca. 93943-5006	3
9. Commanding Officer Navy Environmental Prediction Research Facilities Attn: Sheldon M. Lazanoff Monterey, Ca. 93943-5006	1

10. Dr. Thomas Vonder Haar CIRA/CSU Foothills Campus Fort Collins, Co. 80523	1
11. Chief of Naval Research Attn: CAPT David C. Honhart 800 North Quincy Street Arlington, Va. 22217-5000	2
12. Superintendent Naval Postgraduate School Attn: Dr. Phil Durkee Monterey, Ca. 93943-5000	1

END

Feb.

1988

DTIC